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THE VASCULAR ANATOMY OF LONG BONES

A RADIOLOGICAL AND HISTOLOGICAL STUDY

BY

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Introduction

In order to understand many of the problems of the normal and morbid anatomy of the skeleton a knowledge of its blood supply is essential.

Angiography of the living subject has increased our knowledge of the normal and pathological vascular anatomy of the soft parts, but the usual procedure gives no information on the vessels of the bones. These are too fine to be visualized by standard contrast radiography

Injection into the spongiosa results in filling of vessels within only a limited region up to the nearest veins leaving the bone. In children, injection into the marrow cavity has resulted in filling of the larger venous trunks throughout the diaphysis.

Most roentgen studies on the vascular anatomy of bones have been performed on post mortem material however

It is the anatomy of the vessels of long bones during the growing period that has been the main object of my studies, since opinions vary greatly especially with regard to the blood supply of the epiphyses.

In particular I have examined by means of angiography the tibia of calf and cow and have also performed similar investigations on some human material. The histological investigations are intended to confirm the roentgen findings, especially with regard to the vascular canals of the epiphyses in calves and human fetuses.

CHAPTER I

Earlier Research

LANGER's great work *Über das Gefässystem der Röhrenknochen* was published in 1876. He examined the human tibia and femur by injecting dye into the vessels, and then making casts of the vascular system. Both macroscopic and microscopic investigations were performed. He studied in detail the vascular network of the periosteum and demonstrated the entry of the vessels into it at the attachments of the muscles, aponeuroses, and fasciae. In the femur these vessels enter the periosteum along linea aspera, and in the tibia along fascia cruris and membrana interossea. The periosteal vessels form rings encircling the bones, and they often consist of an artery accompanied by two veins. There are also longitudinal vessels connecting the periosteal rings, and producing a periosteal vascular network which, in both bones, has anastomotic connexions with the capsular vessels. The periosteal arteries also anastomose with the large arteriae nutriciae before these enter the nutrient canals. The vessels supplying the epiphyseal perichondrium arise from the capsular vessels, and are particularly obvious on the femoral condyles, where they are radially arranged on the outer surfaces. While the epiphyseal plate persists, the perichondrial vessels of the epiphyses have no connexion with the periosteal vessels. The periosteal vessels give off branches that penetrate into the bone, and these branches are largest in the metaphyseal regions. In the epiphyses the vessels from the perichondrium enter chiefly on the lateral and medial sides, and, in the case of the lower femoral epiphysis, in area intercondylaris.

By squeezing the diaphysis with a powerful forceps, LANGER demonstrated the paths by which the blood leaves the bone, viz., vena nutricia and the veins draining the metaphyses. Another of his experiments was to inject a resinous substance into the bone, thereby obtaining a cast of the veins draining it. In the lower femoral epiphysis the largest veins leave the bone posteriorly in area intercondylaris, and in the upper tibial epiphysis the largest veins are found in area intercondylaris anterior. The intra-osseous veins are very thin-walled. Outside the bone valves are present. The vascular canals usually contain an artery and one vein, but after leaving the bone the vein commonly branches into two vessels.

LANGER demonstrated communications between the vessels of the marrow cavity and those of the periosteum via vascular canals in the cortex viz, the Haversian canals. These canals are largest in the metaphyseal regions.

LANGER also demonstrated that vena nutricia of the diaphysis divides into several branches as it approaches the metaphysis, there to anastomose with extra-osseous vessels entering via the cortical canals.

LANGER also described vascular canals in the epiphyseal cartilage. He examined the distal femoral epiphysis of a 5½-months fetus, and pointed out that the arrangement of these canals corresponds with that of the vascular canals of the adult bone. In the canals he described an artery and one or two veins. He maintained that the arteries within the canals are end arteries. He also showed that some of the canals penetrate to the diaphysis. The earliest stage at which Langer demonstrated vascular canals in the cartilage was in a 3 months fetus.

LANGER demonstrated vascular channels penetrating the epiphyseal plates, and was of the opinion that these are epiphyseal vessels. In a new born infant he found 15–20 such vascular canals in the lower femoral epiphyseal plate. These canals contain the same vessels as the cartilage canals in general. LANGER also pointed out that vessels perforating the epiphyseal plates are found in horses and cattle.

From LANGER's impressive work it is difficult to obtain a clear picture of the large intramedullary vessels, however Not until roentgen methods were introduced did this become possible.

The first to carry out extensive investigations on the anatomy of the vessels of the bones by contrast radiography was LEXER at the beginning of the twentieth century With a number of collaborators he injected into the osseous arteries contrast medium consisting of mercury and terpentine. His experiments were carried out on human material and the injections were as a rule made into one arteria carotis, the contralateral vena jugularis having been opened The procedure was sometimes complemented by injection directly into the great arteries of the extremities. On completion of the injection stereoscopic radiograms of the skeleton were taken first with the periosteum in situ and then after removing it. In children 3 vascular regions were easily distinguished, the epiphyseal the metaphyseal and the diaphyseal According to LEXER the branches of arteria nutricia of the diaphysis only exceptionally penetrate as far as the epiphyseal plates here arteries from the metaphyseal region are responsible for the blood supply He maintained that a few of the metaphyseal arteries branch towards the epiphyseal plates, and penetrate them The arteries enter the epiphyses at the attachments of the joint capsule and ligaments, and the epiphyseal vessels converge from all sides upon the ossification centre. This is also the case in the apophyses. Some of the epiphyseal vessels give off

branches to the joint cartilage before entering the ossification centre. Some of the vessels turn towards the epiphyseal plates and penetrate them The three groups of vessels anastomose more and more with increasing age. The region supplied by arteria nutricia diminishes as growth proceeds, and instead the metaphyseal arteries increase in number Numerous anastomoses develop between the three groups of vessels towards the end of growth. LEXER maintained that in the adult arteria nutricia of the diaphysis is considerably less significant than the arteries of the epiphyseal and metaphyseal regions.

In 1906 BIDDER described vascular canals of epiphyseal cartilage in growing children. As a rule he found an artery and two veins in the canals, and considered the arteries to be end arteries. He also demonstrated vascular canals piercing longitudinally the epiphyseal plates, and providing connexions with diaphyseal vessels. He maintained that these canals played a significant part in the nutrition of the cartilage and in the ossification of the epiphyses. BIDDER assumed that there were also vessels perforating the apophyseal plates, but never succeeded in demonstrating them.

These three researchers were thus of the opinion that even during the growing period there are anastomoses between the vessels of the epiphyses and metaphyses, via vascular canals perforating the epiphyseal plates. Most later workers however deny the existence of such vascular connexions.

In 1921 GRÉGOIRE and CARRIÈRE carried out an investigation on infants aged 0–2 years. They injected cinnabar or red lead and terpentine into the aorta, and reported that the branches of arteria nutricia of the diaphysis did not reach the epiphyseal plates, and that the metaphyses were supplied by metaphyseal arteries. They were unable to state whether anastomosis took place between these two groups of vessels, but they denied the existence of anastomoses between periosteal and medullary vessels. They considered the epiphyses to be devoid of vessels, since they assumed they were made up of non vascular hyaline cartilage.

In 1924 NUSSBAUM introduced dye and contrast medium into the arteries of the skeleton, by injection into the aorta, and then treated the specimens by Spalteholz s technique. (In this, the bones are rendered transparent, and the blood vessels are seen filled with dye.) NUSSBAUM claimed that during the growing period there are no connexions between epiphysis and diaphysis. He regarded the vascular system of the epiphysis to be completely independent. The vessels in the cartilage canals he regarded to be end arteries until the appearance of the ossification centres, when he claimed that anastomoses developed

H. A HARRIS (1930) injected carmine gelatine into the great arteries in children and young animals, and then examined the long bones. He demonstrated

arteries in the epiphyses, even during the cartilaginous stage, but never found any in the epiphyseal plates which he regarded as a barrier

In 1932 RUBASCHEWA and PRIWES published an account of a roentgen investigation on the vessels of long bones of adult dogs and puppies They used white lead or red lead in liquid paraffin and terpentine. In the case of the anterior extremities injection was made into arteria axillaris, and with the posterior extremities into the aorta immediately above the bifurcation The bones were examined after removal of the soft parts, in the same manner as Lexer employed. They concluded that the branches of arteria nutricia reach as far as the epiphyseal plates, and there anastomose with metaphyseal vessels. In the epiphyses they demonstrated several vessels passing from the perichondrium in towards the centre. In the distal femoral epiphysis they found that the largest vessels enter posteriorly in area intercondylaris, and branch in stellate fashion In the upper tibial epiphysis the largest vessels enter in area intercondylaris anterior and posterior These researchers are of the opinion that in the young animal the epiphyseal plate constitutes a total barrier isolating the epiphysis from the diaphysis. Anastomoses develop they maintain with increasing age, as the epiphyseal cartilage disappears.

In 1951 DE MARNEFFE published a work with the title *Recherches sur la vascularisation osseuse* based on extensive morphological and experimental investigations on rats, guinea pigs, rabbits, and dogs. He employed several techniques.

1 Injection of India ink (25 per cent suspension in physiological saline) into the aorta of living animals. The bones were examined post mortem both macro- and microscopically after considerable preparation.

2 Injection of barium sulphate in gelatine solution, by the same method as 1 The isolated skeletal parts were radiographed before and after decalcification

3 Casts of the vessels were prepared after injection of plastic substances such as Neoprene-Latex

DE MARNEFFE reports that the branches of the diaphyseal arteriae nutriciae of the femur and tibia extend as far as the epiphyseal plates, where they branch to form a rich subchondrial network. These longitudinal branches he regards as end arteries. In addition the main trunk and major branches of arteria nutricia give off transverse branches that anastomose with each other

DE MARNEFFE describes a large venous trunk in the diaphysis, into which veins from the capillary network drain. This trunk is connected with vena nutricia. In addition, there are large venous trunks posterior to tuberositas tibiae that drain into large metaphyseal veins. These latter vessels he interprets as a special diaphyseal venous system

According to DE MARNEFFE, the epiphyses are supplied by one or more arteries and their accompanying veins.

The capillary system of the epiphyses is built up in the same manner as that of the diaphyses He maintains that the vascular canals of the cartilage convey vessels bound for the ossification centre and not concerned with the nutrition of the cartilage. He denies the presence of vessels in the epiphyseal plates. He thus claims that during the growing period the vascular systems of the epiphysis and diaphysis are separate. The compact bone is supplied by the medullary and periosteal networks, and DE MARNEFFE is of the opinion that these are quite distinct. He has also noted that the compact bone of the upper diaphysis (tibia and femur) is largely supplied by medullary vessels, whereas the compact bone of the lower diaphysis receives its blood supply mostly from the periosteal network. Fig 1 is a diagram of the tibial vessels of a rabbit, taken from DE MARNEFFE's book.

HULTH (1956) carried out investigations on the arteries and veins of caput femoris from human adults. The arteries he filled with contrast medium by injection of cinnabar into arteria circumflexa femoris medialis. The veins were filled with India ink by intra-osseous injection into the femoral head. He found that arteries are always accompanied by veins. In patients with medial fractures of the femoral neck he made intra-osseous injections of contrast medium into the head fragment. In cases in which he obtained no filling of the extra osseous veins he concluded that both arteries and veins to the head were torn And in these cases necrosis of the head took place.

Comprehensive research has been carried out in recent years by TRUETA and collaborators. The main object of their attention has been the upper part of the femur They used Micropaque, injecting it into major arterial trunks. Both standard and micro-roentgen methods were employed, together with histological investigation TRUETA also used the transparency technique of Spalteholz after injection of 2 per cent Prussian blue. He had access to much post mortem material consisting of children of all ages, and classifies these as follows,

1 Birth–4 months,
2. 4 months–4 years (infants)
3 4–10 years (intermediate)
4 10 years onwards (pre-adolescent)
5 Adolescent.

At birth, the ossification of the femur has reached the region of the future neck and trochanter major In newly born infants vessels from the metaphysis penetrate in their medial part those cartilage cells that later are to form the epiphyseal plate. This is a large group of vessels, which run vertically In addition the head receives vessels that run horizontally from the lateral side

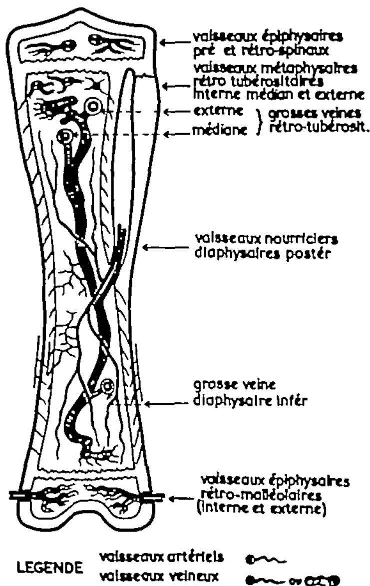


Fig. 1 Blood vessels of the tibia of rabbit. (After de Marneffe.)

into the epiphysis. There are also irregular vessels entering from ligamentum teres.

At 4 months at about the time the ossification centre arises, TRUETA states that the vessels from ligamentum teres disappear At 8 months the ascending metaphyseal arteries have diminished in number and the remaining ones enter the epiphysis after having perforated the periphery of the epiphyseal plate. *The lateral vessels are still large.*

In the third age group the metaphyseal vessels have disappeared, and the epiphyseal plate has become a total barrier The epiphysis is supplied only by the lateral group of vessels.

In the fourth group vessels have again appeared in ligamentum teres. In the adult the barrier formed by the epiphyseal plate is broken, and anastomoses develop with the vessels in the metaphyseal region.

TRUETA is of the opinion that the epiphyseal plate is quite devoid of vessels. Nutrition of the cartilage is derived from the vessels supplying the ossification centre, and from below from the richly vascular metaphysis.

TRUETA and HARRISON (1953) investigated the upper femur of human adults of 20–100 years of age, and were unable to demonstrate regression of the skeletal vessels with advancing age.

LEWIS (1956) carried out experiments on young rabbits and rabbit embryos. He injected dye paste into major arteries, and then examined histologically the long bones. He reports that initially the metaphysis is supplied solely by arteria nutricia of the diaphysis, but the metaphyseal arteries take over this function as the bone grows. He was unable to demonstrate any vessels perforating the epiphyseal plates.

DALE and W R. HARRIS (1958) investigated monkeys. They introduced a cannula into the left ventricle of living animals. First they injected vasodilatory and anticoagulant drugs, and then a mixture of India ink in 5 per cent gelatine. The animals were then killed, and the epiphyses dissected out, fixed in formalin and treated by Spalteholz s technique. DALE and HARRIS distinguish two types of epiphysis, (1) those entirely surrounded by joint cartilage, and (2) those only partially enclosed by joint cartilage. In (1) vessels entering the epiphysis must penetrate the perichondrium surrounding the epiphyseal plate. In (2) the blood vessels enter the epiphysis directly without coming into contact with the perichondrium of the plate. These researchers, too believe the epiphyseal plate to form a barrier since *they have never found any vessels passing through it.*

ROGERS and GLADSTONE (1950) examined the distal part of the human femur at different ages. They paid particular attention to the vascular foramina, which they classify into supracondylar condylar and intercondylar The inter condylar group is especially large, and they term it area cribrosa vasorum intercondyloideae femoris. They demonstrated that both arteries and veins pass

through all these foramina. They examined the arteries after injecting a mixture of mercury and terpentine into arteria femoralis. In children they found that the arteries of the epiphysis converged on the ossification centre. They mention nothing of vessels perforating the epiphyseal plate. The considerable blood supply of the distal portion of the femur they consider to prevent necrosis in fractures in this region.

Most investigations on the vascular anatomy of long bones are concerned chiefly with the arteries HASHIMOTO (1935 1936) has also carried out considerable research on the veins. He used adult rabbits, vital staining the vessels and subsequently treating the preparations by the transparency technique. He performed both macro- and microscopical examinations. He describes a large vein running from metaphysis to metaphysis, about which the arteries wind. The vein has anastomotic connexions with the extra-osseous venous network, via the main vena nutricia of the diaphysis, and the large veins draining the metaphyseal regions Concerning the finer intramedullary branches, he describes peripheral venous sinuses into which the arterial capillaries open The peripheral sinuses flow into a larger sinus that opens into the large vein above-mentioned. Haematopoiesis takes place outside the peripheral sinuses, and the blood corpuscles burst through the single-layered sinus wall and enter the lumen. In the yellow marrow the peripheral sinuses are atrophic.

DOAN (1922) demonstrated a shunt between the arterial capillaries and the larger sinus, which enables the blood to pass from the arteries to the veins without entering the peripheral sinuses

ECOIFFIER PROT GRIFFE, and CATACH (1956) investigated the veins of long bones of adult and growing rabbits. They injected Micropaque into the bones, and thus filled the intra-osseous veins. The preparations were examined radiologically (including micro-roentgen investigation) and histologically They too demonstrated a central venous trunk anastomosing with the extra-osseous veins in the metaphyses and via vena nutricia of the diaphysis. Secondary branches, which have anastomotic connexions with the primary venous channels, drain into the main trunk

They point out that the capacity of the veins is much greater than that of the arteries, and that the veins fulfil a double function draining the tissue in the ordinary way and also serving to collect the products of the bone marrow In growing animals the primary channels are more numerous than in the adults. The epiphyseal vascular system they consider to be isolated from that of the diaphysis the epiphyseal plate constituting a barrier

SPIESS (1950) injected contrast medium (Perabrodil) into the bone marrow of living puppies and adult dogs. He studied the drainage channels, which he found to be greatest in the metaphyseal regions. He was unable to distinguish any vessels penetrating the epiphyseal plates which he regards as a barrier

Ratti Aguzzi and Marley (1956) carried out extensive research on the venous endo-osseous circulation in living subjects (osteomedullography) They injected contrast medium (Joduron Urograf and Pielosil) into the bone marrow of the metaphyses of children and adults, by means of a sternal puncture needle. They often obtained filling of the large venous trunk of the diaphysis and its exit paths via the main vena nutricia and the metaphyseal veins. Among children they obtained opacity of the ossification centre which they attribute to retrograde filling from the capsular network of veins. The epiphyseal plates they regard as a barrier through which contrast medium cannot pass Occasionally they obtained filling of another type of vessel, which they term the reticulo-vascular type —fine vessels within the endosteum. In these cases the

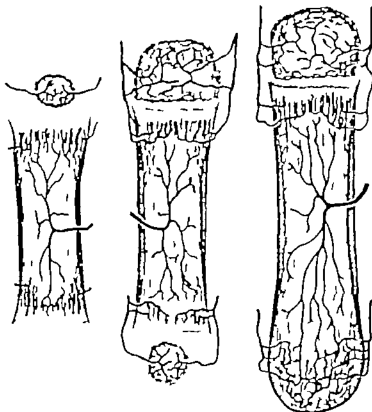


Fig 2 Blood vessels of a long bone during growth, and in adulthood (From *Textbook of Histology* Maximow and Bloom.)

large venous trunks of the marrow were not filled, the contrast medium leaving the bone via fine cortical paths They conclude that this picture is seen when the point of the needle is lying in the region of the endosteum

Modern research thus denies the presence of anastomoses between epiphysis and diaphysis during the growing years (with the exception of that of Trueta, in the case of the upper epiphyseal plates of the femur of children aged less than 4 years) and this is the predominating teaching in all textbooks of anatomy and histology

In most textbooks, the cartilage within the epiphyses is described as avascular The vessels are claimed to penetrate into the epiphyses only when the ossification centres arise. MAXIMOW and BLOOM write, in their *Textbook of Histology* (1957) that the cartilage is an avascular tissue and if vessels are present they are only passing through the cartilage to some other tissue. Only in the perichondrium are there any vessels that are concerned with the nutrition of the cartilage. Thus, during the cartilaginous stage, the central parts of an epiphysis are poorly supplied with blood, and are the parts which are first become calcified. Not until ossification has commenced do vessels start to enter the ossification centre. BUCHER is of the same opinion in his *Histologie und Mikroskopische Anatomie* (1956) as is also BARGMANN in his *Histologie und Mikroskopische Anatomie des Menschen* (1956)

Fig. 2 is taken from MAXIMOW and BLOOM's textbook and shows the plan of the vascular system during growth and adulthood.

CHAPTER II

Material

Investigations have been carried out on calves and cows, and on a small human series.

The *calves* were aged 1 day–2 months. In the calf the preparation extended from above the knee joint to below the ankle joint, all soft parts except the skin being present. The vascular system of the tibia was the main object of study but the distal femoral epiphysis was also examined in these preparations. A few investigations were also carried out on the calf humerus and femur after removal of the muscles.

In the *cow* the tibia only was investigated.

The *human material* was very limited. I have examined immature and full-term fetuses, and cases aged 2 months, 6 months, 10 months, 7 years, and 11 years.

CHAPTER III

Technique

Selective angiography by injection into artery or vein in canalis nutricius and angiography via arteria or vena femoralis were carried out. A few investigations were performed by intra-osseous injection.

1 *Injection into vasa nutricia*

Selective investigation of these vessels has previously been made in order to obtain casts of the intra-osseous vessels, or to fill them with dye but as far as I know the procedure has never been employed with contrast media for the purposes of serial roentgenography

I have repeatedly succeeded in filling *vena nutricia* in the tibial diaphysis of the calf by cannulation of canalis nutricius. The vein occupies almost the entire lumen of the canal which is clearly visible on screening I introduced the cannula during screening after puncture of the soft parts.

Arteria nutricia of the tibial diaphysis of the calf were filled with contrast medium after dissection. As a rule I dissected out arteria tibialis anterior opened it up and introduced the catheter or cannula through the origin of arteria nutricia.

The following method was also employed. The catheter was passed down the unopened arteria tibialis via arteria poplitea as far as arteria nutricia of the tibial diaphysis. When the tip of the catheter reached the origin of this branch I ligated arteria tibialis above and below the tip of the catheter (N B In the calf arteria nutricia commonly gives off one or two small branches to the soft parts before it enters the foramen and these must be tied off)

In the *tibial epiphysis* I dissected down to the largest foramina nutricia, and introduced a cannula into the vein or artery The tip of the cannula must be passed beyond the valves that are always present just outside foramina nutricia

Selective angiography of the *tibial epiphyses* is very difficult because the vessels are extremely narrow and because there is no great artery or vein which may serve as starting point

In investigating the upper tibial epiphysis, arteria genu medialis, which passes obliquely downwards and forwards from the medial side of the joint capsule

may be traced A branch of this artery passes through the infrapatellar pad of fat and continues to the largest nutrient foramen, which lies medially in area intercondylaris anterior The artery is accompanied by two veins. It is necessary to dissect to this foramen, and try to enter the fine vessels

I confirmed that the cannula or catheter was lying properly in the lumen of vessel by injecting physiological saline. When the instrument had been correctly introduced, I often fixed it by dropping melted paraffin wax about the site of injection

The contrast medium used for selective angiography was 70 per cent 'Urokon (Pharmacia) This consists of the sodium salt of 3 acetylamino-2 4 6 tri iodobenzoic acid.

The contrast medium must be water soluble. Suspensions of the dionosil and barium-sulphate type are too thick dionosil passes through the capillaries only with the greatest difficulty and the barium suspension does not pass them at all

The exposures were made on roll film using Gidlund's single plane changer With this apparatus it is possible to make several exposures per second during the injection The first exposure was made at the commencement of the injection which was performed by hand with a record syringe. Occasionally during the course of the experiment I made a brief pause in the injection to rotate the preparation in order to obtain both frontal and lateral projections.

2 Injection into arteria and vena femoralis

This procedure was followed in a few cases, and barium-sulphate suspension (equal quantities of Micropaque and physiological saline) was employed. The thigh was divided, and the skin left in place. The particles in a barium suspension are smaller than red blood cells, but this contrast medium does not pass through the capillaries, probably owing to agglutination of the particles.

Injection into the femoral vein under high pressure causes overfilling with valvular insufficiency as result. Contrast medium can then enter the intra osseous veins.

The advantage of selective angiography is that it enables the examiner to trace the path of the contrast medium through the intra-osseous vessels. The water-soluble contrast medium passes the capillaries without difficulty The disadvantage is that the highly concentrated iodine salts that are used diffuse out of the vessels after only a short time, so that the outlines become blurred and the solution may even crystallize in the vessels if a long pause is made during the injection

An advantage of the Micropaque method is that the barium suspension is inert, and remains unaltered in the vessels. Another advantage is that different vascular regions are filled simultaneously in the same preparation A dis

advantage is that it is difficult to examine the skeletal vessels in detail owing to filling of vessels in the overlying soft parts. The films are read more easily when the soft parts have first been removed. Further small vessels may fail to fill owing to the nature of the contrast medium

3 *Intra-osseous injection*

Intra-osseous injection was performed in a few of the human preparations in which selective angiography had been unsuccessful. A cannula was introduced into the spongiosa, and Urokon injected after withdrawal of the stilette. It has been found that blood vessels filled by intra-osseous injection are always veins the lumina of the skeletal veins are so much greater than those of the arteries that the contrast medium flows into the veins.

In all investigations involving intravascular injection it must be borne in mind that the injected fluid takes the path of least resistance Conclusions may therefore be drawn from positive roentgen findings, but negative findings should be assessed with caution.

CHAPTER IV

Roentgen Investigations in Calf

1 *The venous system of the tibial diaphysis*

The vein which is single, fills out almost the entire lumen of canalis nutricius. Externally the foramen opens posteriorly on the lateral side of the tibial diaphysis, about 3 cm below the epiphyseal line. It is fairly easily accessible, since, in the calf the fibula is absent or rudimentary In the new-born animal the canal is about 5 cm in length. The internal opening lies at the junction of the upper and middle thirds of the diaphysis. Vena nutricia to the diaphysis arise from vena tibialis anterior

After vena nutricia has passed the internal opening of the canal it gives off three large ascending branches. The main vein then proceeds downwards, becoming rapidly narrower until at about the middle of the diaphysis, it divides into 2 or 3 descending branches. All these ascending and descending branches and the main vein itself give off many small branches that in turn divide repeatedly

On injection into vena nutricia of the diaphysis the contrast medium traverses a network of small veins in the upper and lower metaphyses, finally to enter longitudinal veins that perforate the epiphyseal plate at its centre. The venous systems of the epiphyses are filled in this manner (Fig 3)

I have seen up to three large perforating veins in the upper epiphyseal plate, and one large vein in the lower plate.

The contrast medium enters one of the major ascending branches of vena nutricia passing behind crista tibiae, traverses a network of vessels, and then enters another fairly large vein. This vessel perforates the apophyseal plate between tuberositas tibiae and the metaphysis, on the lateral side of the tuberosity Within the cartilage this vein continues as two parallel metaphyseal veins that traverse the cartilage and pass to the periosteum of the metaphysis, where they are easily seen (Fig 4) Between these veins lies an artery

In addition to the metaphyseal veins of tuberositas tibiae the network of veins in the ossification centre of tuberositas tibiae is also filled and when the contrast medium has penetrated this network, a vein perforating the apophyseal

plate between tuberositas tibiae and the epiphysis becomes filled. This latter vein has connexions with the epiphyseal veins.

Tuberositas tibiae is therefore a meeting place of epiphyseal metaphyseal and diaphyseal veins (Fig 4)

2. *The venous system of the tibial epiphyses*

Upper epiphysis

The largest foramen nutricium is situated in area intercondylaris anterior slightly medial to the mid line. This contains 2 veins and one artery branches of the capsular vessels. The larger vein gives off first a large branch which passes through the apophyseal plate on its way to tuberositas tibiae. (Fig. 5) It then continues towards the centre of the epiphysis, where it branches in all directions. It communicates with other veins passing through smaller foramina at eminentia intercondylaris and area intercondylaris posterior

From the main epiphyseal vena nutricia arise longitudinal perforating veins which penetrate the epiphyseal plate, and pass to the metaphyseal venous net work. Thus on injection of contrast medium into veins of the upper tibial epiphysis, veins perforating the epiphyseal and apophyseal plates are also filled (Fig 5) These are the perforating veins described on page 20 They are primary branches of the central veins of the epiphysis. I have observed that on injecting into vena nutricia of the diaphysis the veins perforating the epiphyseal plate are not filled until after the contrast medium has passed through a network of small veins in the metaphysis. The perforating veins then continue direct to the great central veins of the epiphysis. Morphologically the perforating veins would seem to belong to the epiphyseal group

Lower epiphysis

Here the largest foramen nutricium is on the anterior surface slightly medial to the mid line Injection of contrast medium into the vein lying in this foramen reveals a system similar to that in the upper epiphysis, with a large vein passing to the centre and there branching in all directions. From this vein runs a longitudinal vein that perforates the lower epiphyseal plate at about its centre (Fig. 6)

I have succeeded in filling the greater intra-osseous venous channels of the entire tibia by injecting contrast medium into the vein of the lower epiphysis (Fig. 6)

3 *The venous system of the lower femoral epiphysis*

There is a large foramen nutricium posteriorly between the condyles of the lower femoral epiphysis. Through this pass large veins that drain into vena



Fig. 3. Calf aged 2 weeks. Cannula lying in canalis nutricius of the tibial diaphysis. Urokon. A, and D, lateral views, B and C, frontal views.

1. Vena nutricia and ascending and descending branches.
2. Vein perforating the lower epiphyseal plate. Before entering this vessel the contrast medium passes through a vascular network in the metaphysis.

Note

The roentgen illustrations are a selection from the serial exposures made during each experiment. They are consequently arranged in chronological order and the course of the contrast medium can therefore be traced. Lateral and frontal views placed together are taken at the same stage.



C



D

A ein is seen lea ing the lower epiphysis by a f ramen nutricium sl ghtly medial to the mid line anteriorly (at 3)

4 Vein perforating the upper epiphyseal plate Via this em contrast medium passes to veins in the epiphysis.

5 Vein passing behind crista tibiae and perforati g the apophyseal plate between tuberositas tibiae a d the metaphysis. It continues to the ossification centre of tuberositas tibiae After passi g throu h a enous network in the tuberositas, contrast medium enters veins perforating the pophyseal plate between the tuberosity and the epiphysis (at 6) and thus passes nto eins in the epiphysis. The epiphyseal veins drain into a vessel leaving by a foramen utri ium (at 7) in area inter ondylaris anterior

N B lso a small metaphyseal ein at 8 filled w th contrast medium



Fig 4 Calf aged 2 weeks. Injection into vena nutricia of the tibial diaphysis by cannulation of canalis nutricius. Urokon

A and D frontal views. B and C, lateral views

1 Vena nutricia.

2. Vein passing behind crista tibiae and filled with contrast medium that has first passed through a venous network



C



D

3 Filling of metaphyseal veins in the lateral part of the apophyseal plate, between tuberositas tibiae and the metaphysis These vessels pass towards the surface of the bone and continue in the periosteum as two parallel veins (at 4)

5 Vein perforating the apophyseal plate between tuberositas tibiae and the epiphysis. Via this, contrast medium enters epiphyseal veins which drain to capsular veins via the large foramen nutricium lying just medial to the mid line in area intercondylaris anterior (at 6) A small vena nutricia can be seen at eminentia intercondylaris (at 7).





Fig. 5 Calf aged 2 weeks. Cannula lying in the vein to the upper tibial epiphysis. Urokon
A, B, and C, frontal views D lateral view

1 Cannula lying in vein to foramen nutricium in area intercondylaris anterior
2. Vein perforating the upper epiphyseal plate.
3 Vena nutricia of the diaphysis filled with contrast medium that has first passed through a network of small veins.



C



D

4 Vein perforating the apophyseal plate between the epiphysis and tuberositas tibiae
5 Vein perf rating the apophyseal plate between tuberositas tibiae and the metaphysis. Only very little cont ast medium has taken this path on this occasion.
Note the extensi e branching of epiphyseal veins and anastomoses between different veins. The ei lying n the small foramen nutricium at eminentia intercondylaris (at 6) is f lled

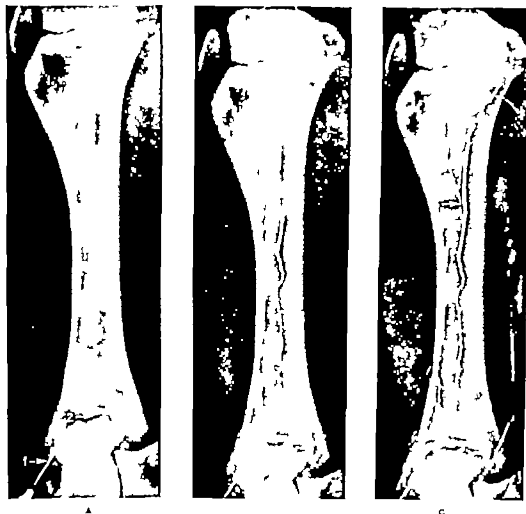


Fig. 6. Calf aged under 2 months. Cannula lying in vein to the lower tibial epiphysis. Urokon. A–D lateral views. E, frontal view.

1 Cannula lying in vein in the antero-medial foramen nutricium.

2. Vein perforating the lower epiphyseal plate and passing directly into vena nutricia of the diaphysis.

3 Ascending branch of vena nutricia of the diaphysis.



D



E

4 Vein perforati g the upper epiphyseal plate filled with contrast medium that has first passed throu h a metaphyseal venous network Epiphyseal veins extending to foramen nutricium in area intercondylaris anterior are filled via the perforating vein

Injection of contrast medium into ein to the lower epiphysis results in filling, via perforating eins, of the entire venous system of the tibia.



A



B



E



F



Fig. 7. Calf 2 weeks. Same preparation as fig. 1
A–E, frontal views. F, lateral view.
Contrast medium has crystallized in vena nutricia of the tibia. On continued injection most contrast therefore passes through vena poplitea. Occlusion of vena femoralis forces the contrast medium into the venous system of the lower femoral epiphysis. Large veins enter centrally via large foramina nutricia in area intercondylaris. Serial radiography discloses the radial arrangement of the branches, which pass to all parts of the epiphysis.



A



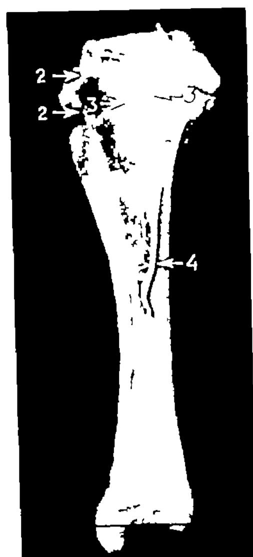
B



C



D



E



F

Fig. 8. Calf 1 day. Injection of Micropaque into vena femoralis. Serial radiography A–D.
A, B, and D, frontal views; C, lateral view.
The tibia isolated, and the periosteum removed. E, lateral view. F, frontal view.
The radial arrangement of the central veins of the lower femoral epiphysis is clearly seen in A–C.
At 1 can be seen veins entering the epiphysis from the perichondrium, and anastomosing with branches of the central veins. Otherwise little is discernible owing to the contrast medium in the soft parts. In the films of the isolated tibia are seen upper epiphyseal veins perforating the apophyseal (2) and epiphyseal (3) plates.
4. Vena centrica of the tibial diaphysis.





A B

Fig 9 Calf 2 weeks. Cannula lying in vena nutricia to the humeral diaphysis. Urokon. Muscles removed. A lateral view B, frontal view
1 Veins perforating the apophyseal cartilage between tuberculum majus and the metaphysis





A B

Fig 10 Calf . weeks Upper part of humerus after injection of Micropaque into vena axillaris. After injection the soft parts, including the periosteum, were removed.

A, frontal view B lateral view

1 Vena nutricia of the diaphysis.

Veins perforating the apophyseal plate between the diaphysis and tuberculum majus.

3 Veins passing to caput humeri via the epiphyseal plate

poplitea. These veins pass to the centre of the epiphysis, and branch in all directions (Fig. 7)

In addition there are a number of smaller vessels in the perichondrium, and these enter the skeleton at various points (Fig 8) The largest vessels are those that enter through the large foramen nutricium however

4 *Simultaneous filling of the epiphyseal and diaphyseal veins after injection into vena femoralis*

A few experiments were made by this method using Micropaque One of these, where the hind leg of a calf was used, is illustrated in Fig 8 The central veins, which enter the lower femoral epiphysis posteriorly in area intercondylaris, are clearly seen The radial arrangement of the branches, which pass to all parts of the epiphysis is obvious and the perichondrial veins, which anastomose with branches of the central epiphyseal vessels, are also seen The perforating veins from the venous system of the upper tibial epiphysis are also clearly demonstrated.

5 *The venous system of the humerus*

The upper part of the humerus of the calf was examined to ascertain whether there are any veins perforating other apophyseal or epiphyseal plates.

Injection into vena nutricia of the humeral diaphysis in a preparation freed from muscles revealed several veins perforating the apophyseal plate and continuing to tuberculum majus (Fig. 9)

Another experiment, in which Micropaque was injected into vena axillaris, showed filling of veins perforating both the epiphyseal plate between caput humeri and the metaphysis, and the apophyseal plate between tuberculum majus and the metaphysis (Fig 10)

6 *The arterial system of the tibial diaphysis*

Arteria nutricia of the diaphysis leaves arteria tibialis anterior at an angle of almost 90° (Fig 11) Immediately after entering canalis nutricius the artery gives off some small branches to soft parts. After leaving the canal it gives off 3 large ascending branches (Fig. 12) The artery then continues to about the middle of the diaphysis, where it divides into two or three descending branches. Both ascending and descending branches give off branches that run longitudinally to the epiphyseal plates. Noteworthy is the tortuous course of the large branches in the middle part of the diaphysis. No branches of arteria nutricia perforating the epiphyseal plates were filled.

On filling of arteria nutricia of the diaphysis with contrast medium the vessels of the richly vascular metaphyseal regions adjacent to the epiphyseal plates and to the apophyseal plate at tuberositas tibiae, quickly become filled.



F g 11 Calf 2 weeks Cannula lying ar teri poplitea Un kon Lateral ew

1 Arteria poplitea
Arteria tibial anterior
3 Arteria nutric of the diaphysis.
4 Small branches to the soft parts, arisin mmediatel bef re the artery enters the anal

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5 *The venous system of the humerus*

The upper part of the humerus of the calf was examined to ascertain whether there are any veins perforating other apophyseal or epiphyseal plates.

Injection into vena nutricia of the humeral diaphysis in a preparation freed from muscles revealed several veins perforating the apophyseal plate and continuing to tuberculum majus (Fig. 9)

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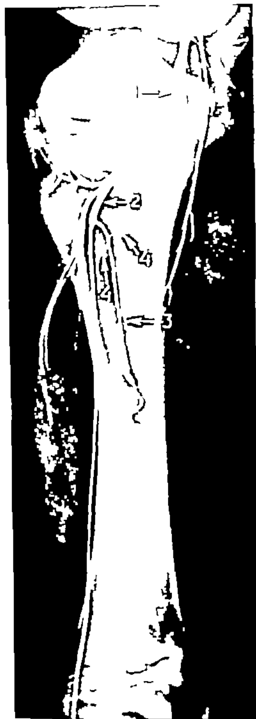


Fig 11 Calf 2 week Can ula lying in ar teria popl tea Urokon Lateral ew

1 Arteria popl tea
2 Arteri tibial anterior
3 Arteria nutricia of the diaphysis.
4 Small branches to the soft parts, arising immed tel before the artery enters the nal

poplitea. These veins pass to the centre of the epiphysis, and branch in all directions (Fig 7)

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5 *The venous system of the humerus*

The upper part of the humerus of the calf was examined to ascertain whether there are any veins perforating other apophyseal or epiphyseal plates.

Injection into vena nutricia of the humeral diaphysis in a preparation freed from muscles revealed several veins perforating the apophyseal plate and continuing to tuberculum majus (Fig. 9)

Another experiment, in which Micropaque was injected into vena axillaris, showed filling of veins perforating both the epiphyseal plate between caput humeri and the metaphysis, and the apophyseal plate between tuberculum majus and the metaphysis (Fig 10)

6 *The arterial system of the tibial diaphysis*

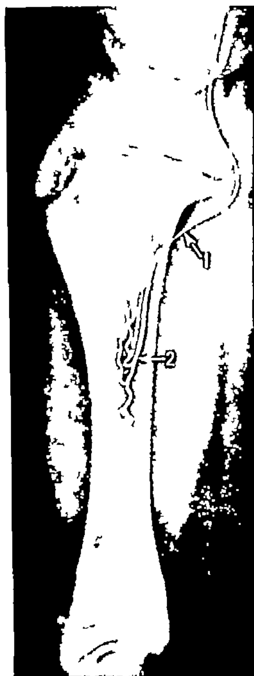
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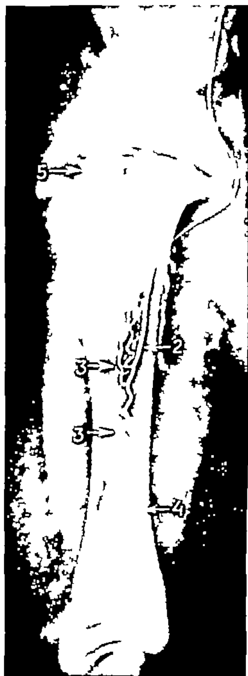
On filling of arteria nutricia of the diaphysis with contrast medium the vessels of the richly vascular metaphyseal regions adjacent to the epiphyseal plates and to the apophyseal plate at tuberositas tibiae, quickly become filled.



Fig. 11. Calf, week. Cannula lying in arteria poplitea. Urokon. Lateral view.

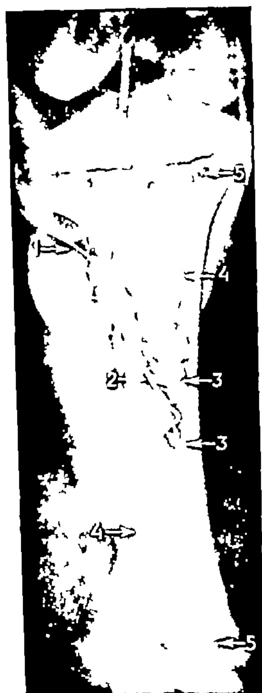
1 Arteria poplitea
Arteria tibialis anterior
3 Arteria nutricia of the diaphysis
4 Small branches to the soft parts, arising immediately before the artery enters the canal





A B

Fig. 12 Calf 2 weeks. Catheter lying in arteria nutricia of the tibial diaphysis. Dionosil.
A, B, and D lateral views. C, frontal view.
1 Catheter
2. Main stem of arteria nutricia



C



D

3 [illegible] scending and descending branches.
4 Longitudinal branches running toward the metaphyses.
5 Contrast medium collected in the metaphyseal regions.



Fig. 13 Calf 2 weeks. Catheter lying in arteria nutricia of the tibial diaphysis. Urokon
A B and E, lateral views. C, D and F frontal views
1 Catheter in arteria nutricia, in foramen nutricium.
2. Arteria nutricia and ascending and descending branches.



3 Metaphyseal cin
4 Ep physeal eins
5 There slight opacity f the ossification centre of tuberositas t biae due to contrast med um

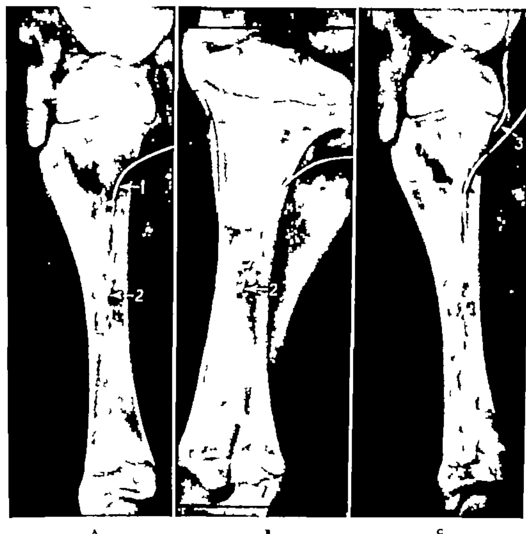


Fig. 14 Calf 2 weeks. Catheter lying in arteria nutricia of the tibial diaphysis. Urokon
A, C, and F lateral views. B, D and E, frontal views.
1 Catheter lying in arteria nutricia in canalis nutricius.
2 Arteria nutricia, and ascending and descending branches.



D E F

3 Vein in upper metaphysis
4 Epiphyseal veins filled from perforating veins.
5 Contrast medium in tuberositas tibiae. Veins are seen in the apophyseal plates.



A B C

Fig 15 Calf 2 weeks. Catheter lying in arteria tibialis anterio the tip level with the origin of arteria utricia of the tibial diaphysis. Ligature abo e and below Urokon
A B, C, and F lateral iews D d E, frontal views
1 T p of the catheter
2. Arteria utricia and bra ches
3 Vei pa sing behind crista tibiae



4 Veins penetrating the apophyseal plates a d entering tuberositas tibiae
5 Vein in foramen nutricium.
6. Metaphyseal vein.
7 Contrast medium escapi g from ena utricia in foramen nutricium of the diaphysis. The vein wa damaged during dissection



F g 15 Calf 2 weeks Catheter lying in arteria tibialis anterior the tip level w th the origin of arteria utricia of the tibial diaphysis. Ligature above and bel w Urokon

A, B, C, and F lateral views D and E, frontal views

1 T p of the catheter

2 Arteria utricia and branches

3 Vei passi g behind crista tibia



4 Veins penetrating the apophyseal plates and entering tuberositas tibiae.
5 Vein in foramen nutricium
6 Metaphyseal vein
7 Contrast medium escaping from vena nutricia in foramen nutricium of the diaphysis. The vein was damaged during dissection

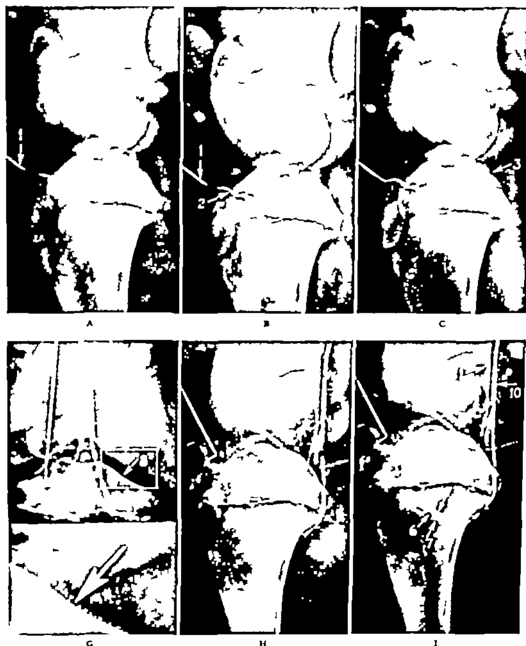


Fig. 16. Calf 2 weeks. Cannula lying in arteria nutricia of the epiphysis, in area intercondylaris anterior. Urokon.

A–E, H, I and L, lateral views. F, G, J and K, frontal views.

1. Cannula.
2. Arteria nutricia running towards the centre of the epiphysis.
3. Retrograde filling, via anastomoses, of an arteria nutricia in area intercondylaris posterior.
4. Contrast filling of the upper part of the ossification centre of tuberositas tibiae.



D C F



J K L

5 Filli g of the metaphysis.
6 Metaphyseal artery
7 Metaphyseal veins.
8 Fringe of cartilaginous vessels. See also G
9 Vena nutricia of the diaphysis.
10 Arteria popl tea.
11 Vena poplitea.

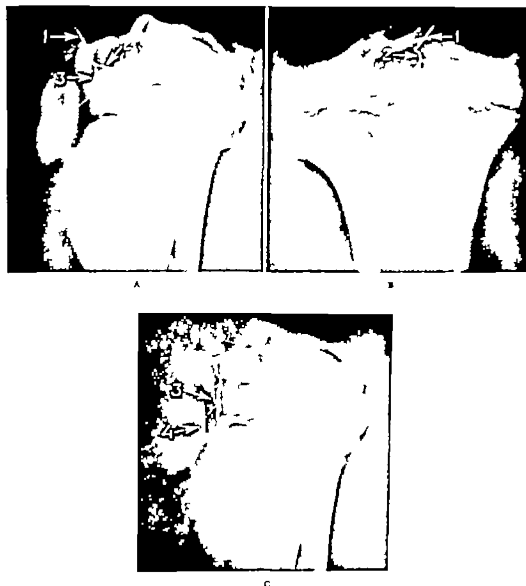


Fig 17 Calf 2 months. Cannula lying in arteria nutricia, in area intercondylaris anterior Urokon A and C, lateral views. B frontal view

1 Cannula
2 Arteria nutricia running towards the centre of the epiphysis.
3 Branch of artery perforating the apophyseal cartilage between the epiphysis and tuberositas tibiae
4 Filling of tuberositas tibiae.

Gradually during the course of injection the entire bone marrow becomes filled with contrast medium and becomes evenly opaque. The capillaries are then filled. The contrast medium penetrates the capillaries and can be traced out into the draining veins (Figs. 13 14 and 15)

The passage of the contrast medium into the metaphyseal and epiphyseal veins is clearly seen, and also its drainage via vena nutricia of the diaphysis. This is best demonstrated when the catheter is not introduced into the actual canal (Fig 15) In this experiment the tip of the catheter is lying in arteria tibialis anterior at the origin of arteria nutricia. The cortical vessels of the tibial diaphysis are too narrow to be visualized by this method. During injection blood can be seen escaping at a few places through the cortex.

After injection into arteria nutricia of the tibial diaphysis, then contrast medium leaves the bone by the following routes,

1 vena nutricia of the diaphysis,
2 the metaphyseal veins,
3 the epiphyseal veins, and
4 the cortical veins of the diaphysis.

7 *The arterial system of the tibial epiphyses*

Upper epiphysis

The largest artery enters through foramen nutricium in area intercondylaris anterior Together with its corresponding vein it passes towards the centre of the epiphysis, and branches in all directions. It anastomoses with arteries that enter by other smaller foramina It also has a branch that perforates the cartilage between the tibial epiphysis and tuberositas tibiae and there are branches perforating the epiphyseal plate.

Fig 16 illustrates an injection by cannulation of arteria nutricia in area intercondylaris anterior The artery passes towards the centre, and is seen to anastomose with another arteria nutricia entering in area intercondylaris posterior This latter vessel appears to be a small branch of arteria poplitea, which is also filled with opaque substance. Contrast medium is seen in tuberositas tibiae and in the upper tibial metaphysis at an early stage during the injection, before the veins are filled this indicates that there are arteries perforating the apophyseal and epiphyseal plates. A metaphyseal artery is also seen to be filled, lying between the parallel veins in the periosteum. In time practically the entire epiphysis becomes filled, and the contrast medium passes into the venous system, both veins and arteries ultimately being filled at the same time.

The contrast medium passes into epiphyseal metaphyseal, and diaphyseal veins.

The vessels of the cartilage surrounding the bone appear as a fine millimetre-thick fringe best seen on the lateral tibial condyle. The vessels are clearly seen

in the actual preparation, glistening through the cartilage. They are particularly obvious after injections when blood is forced out into them

Fig 17 illustrates another injection into arteria nutricia of the upper tibial epiphysis of the calf Here an artery is clearly seen perforating the apophyseal plate between the epiphysis and tuberositas tibiae.

Fig 18 illustrates injection into an artery supplying the *lower tibial epiphysis* Here, too is seen a fairly large artery passing to the centre and branching in all directions. The entire epiphysis ultimately becomes filled with contrast medium which also enters the metaphysis via perforating vessels. It is impossible here to distinguish between perforating arteries and veins. Vena nutricia of the diaphysis are clearly filled, and contrast medium is seen in the two venae tibiales anteriores and in arteria tibialis anterior

Contrast medium injected into arteria nutricia of the epiphyses leaves the bone by the following routes,

1 anastomosing arteries,
2. epiphyseal veins,
3 metaphyseal veins and
4 diaphyseal veins.

8 *The arterial system of the femoral diaphysis*

There is only one canalis nutricius in the femoral diaphysis of the calf Externally it opens posteriorly on the lateral side of the diaphysis, at the junction of the middle and lower thirds. It is directed obliquely upwards, and the canal is very short. Arteria nutricia continues to the middle of the diaphysis, where it divides into tortuous ascending and descending branches which extend to the epiphyseal plates and to the apophyseal plate at trochanter major The metaphyseal regions adjacent to the epiphyseal and apophyseal cartilages are richly vascular

Fig. 19 illustrates an injection into arteria nutricia of the femoral diaphysis of the calf The muscles have been removed.

9 *Simultaneous filling of arteries of the tibial epiphyses and diaphysis after injection into arteria femoralis*

A few experiments were done. The leg was divided through the thigh and the skin was left intact.

Fig 20 shows the isolated tibia after the injection. The muscles and periosteum have been removed. Arteria nutricia of the diaphysis is evidently the largest artery of the tibia. The rich vascularity of the metaphyseal regions is clearly seen. The epiphyseal arteries are also obvious. In the upper epiphysis, arteries deriving from the perichondrium are also filled these are most readily seen at the lateral tibial condyle.

10 *Simultaneous filling of arteries of the lower femoral epiphysis and upper tibial epiphysis after injection into arteria poplitea*

In this experiment (fig 21) the leg is divided below canalis nutricius of the femoral diaphysis. Canalis nutricius of the tibial diaphysis is occluded. Contrast medium cannot therefore enter via the diaphyseal arteries.

The arteries entering the lower femoral epiphysis in area intercondylaris posterior and the upper tibial epiphysis in area intercondylaris anterior are seen well filled These are the largest arteries of these epiphyses. They pass towards the centre, and branch in all directions.

In addition the perichondrial arteries are filled. These branch at the peri pheries of the epiphyses, and anastomose with branches from the central arteries of the epiphyses. Filling of the metaphysis also takes place via metaphyseal arteries.



Fig 18 Calf 2 weeks. Cannula lying in arteria nutricia of the lower tibial epiphysis. Urokon. A, B D and F frontal views. C, and E, lateral views.

1 Cannula.

2 Arteria nutricia.

3 Vessels perforating the epiphyseal plate.



4 Filling of the metaphysis.
5 Vena nutricia of the diaphysis.
6. Venae tibiales anteriores.
7 Arteria tibialis anterior

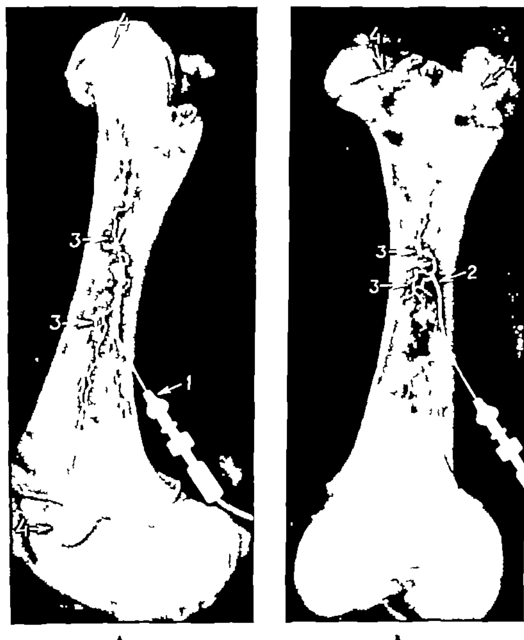


Fig 19 Calf 2 weeks. Cannula lying in arteria nutricia of the femoral diaphysis. Muscles removed. Urokon.

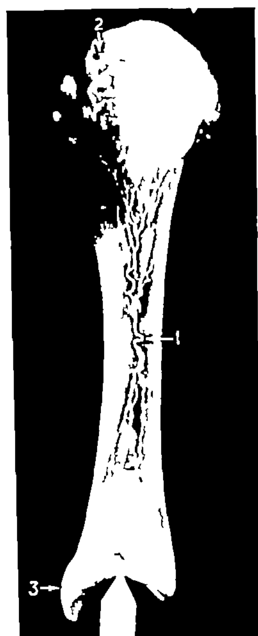
A, lateral view B frontal view

1 Cannula

2 Arteria nutricia.

3 Ascending and descending branches.

4 Filling of the metaphyses adjacent to the epiphyseal and apophyseal cartilage.



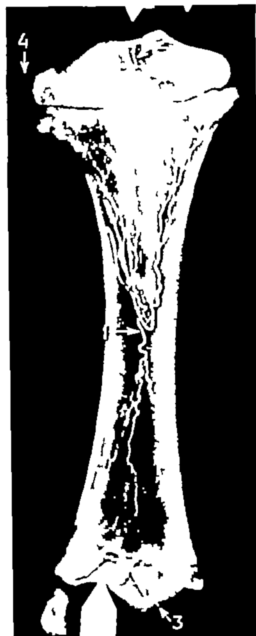


Fig. 27 Calf 2 weeks. The arterial system of the tibia filled by injection of Micropaque into arteria femoralis. The soft parts, including the periosteum, are removed.

A lateral view B frontal view

1 Arteria nutricia of the diaphysis.

2 Arteria nutricia of the upper epiphysis.

3 Arteria nutricia of the lower epiphysis

4 Arteries entering the upper tibial epiphysis from the perichondrium.



A

Fig 21 Calf 2 weeks. The lower femoral and upper tibial epiphyses after injection of Micropaque into arteria poplitea. A, and B, lateral views. C, D and E, frontal views. In B and C the muscles and joint capsule are removed.
In D and E the periosteum and perichondrium are removed.



a



c



D



E

1 Cannula lying in arteria poplitea.
2 Arteries running towards the centre of the femoral epiphysis.
3 Arteries running towards the centre of the tibial epiphysis.
4 Perichondrial arteries

CHAPTER V

Roentgen Investigations in Cow

1 *The venous system of the tibial diaphysis*

Canalis nutricius of the tibial diaphysis of the cow is situated more distally than that of the calf the distance between the external opening and the upper epiphysis being about 1/4 of the length of the diaphysis (in the calf it is about 1/5 of this length) The lumen is narrower than in the calf

The main vena nutricia and its major branches are largely similar to those of the calf

Fig 22 illustrates an injection of contrast medium into vena nutricia of a young cow in which the apophyses and epiphyses have partially united. After leaving the canal the main vein gives off narrow ascending branches. Just below the middle of the diaphysis it becomes narrower and gives off fine descending branches. Small branches arise from the main vein and from the ascending and descending branches. The contrast medium leaves the bone via cortical veins in both upper and lower metaphyses. In the upper metaphysis the vein can be seen passing behind crista tibiae. As in the calf contrast medium injected into vena nutricia of the diaphysis passes a fine venous network before this vein is filled. At the apophyseal plate the vein enters the parallel veins in the periosteum of the lateral side of the metaphysis. Filling of the epiphyseal veins was not achieved in this experiment the cortical veins draining the metaphyseal regions are so large that the contrast medium leaves the bone by them alone.

In another experiment (Fig 23) in which contrast medium was injected into vena nutricia of a tibia the muscles of which had been removed the opaque substance was also seen to leave the bone via cortical veins in the metaphyseal regions. Furthermore a cortical vein of the middle of the diaphysis is seen filled at one point, revealing a vein situated in the periosteum

2. *The venous system of the upper tibial epiphysis*

The foramen nutricium situated in area intercondylaris anterior is also very obvious in the cow

Injection of contrast medium into the vein entering by this foramen reveals its course towards the centre (Fig 24) The vein branches in all directions, and anastomoses with the intra-osseous veins of the metaphysis. The contrast medium leaves the bone via epiphyseal and metaphyseal veins, and, because it passes so readily through these channels, filling of vena nutricia of the diaphysis is not obtained.



Fig. 22. Young cow. Catheter lying [illegible] vena [illegible] of the tibial diaphysis. Urokon. A, B and D frontal views. C, lateral view.
1 Vena [illegible] and ascending and descending branches.



C



D

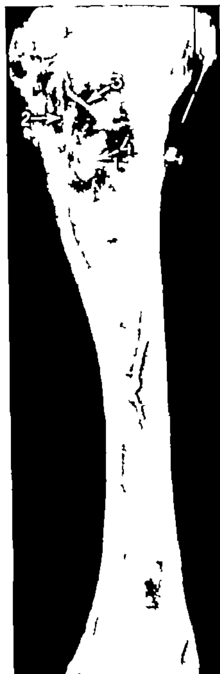
2. Vein passing behind crista tibiae, at 3 crossing the apophyseal plate to continue as two periosteal veins on the metaphysis.
4 Veins of the soft parts, filled via cortical paths.



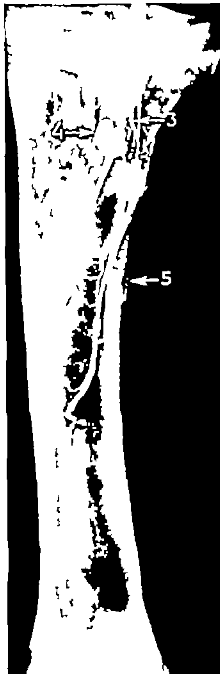
Fig. 23 Cow. Cannula lying in vena nutricia of the tibial diaphysis. Muscles removed. Urokon. A, and C, lateral views. B, and D, frontal views.

1 Vena nutricia with ascending and descending branches

2 Vein passing behind crista tibiae



C



D

3 Periosteal vein on the upper metaphysis
4 Contrast medium outside the bone
5 Periosteal vein of the diaphysis

3 *The arterial system of the tibial diaphysis*

The main artery and its major branches closely resemble those of the calf but the longitudinal branches running towards the epiphyseal plates have be come much less pronounced in the cow and do not extend to the epiphyses. In the metaphyseal regions branches of arteria nutricia of the diaphysis anastomose with metaphyseal and epiphyseal arteries.

The dense contrast filling of the bone marrow obtained on arteriography in the calf is never seen in the cow This indicates that in the cow the capillary system of the marrow has become greatly reduced.

In the muscle-free preparation arteria nutricia is seen as a large vessel (Fig. 25) After leaving the canal, the main artery gives off two tortuous, ascending branches, and then itself continues downwards to divide, slightly below the middle of the diaphysis, into three descending branches. In the metaphyses the longitudinal branches divide to form a fine network and the contrast medium leaves the bone via cortical paths in the metaphyseal regions.

Fig. 26 illustrates injection of contrast medium via a catheter introduced into arteria nutricia of the diaphysis. The muscles are in situ In this experiment the main vena nutricia of the diaphysis was also filled. In fig 26 A contrast medium is present only in the artery but in the subsequent films the main vein is seen as a fairly large vessel accompanying it. Contrast medium must there fore have penetrated the capillary system. This has taken place without be coming obvious on the films which indicates that the capillary system is much smaller than in the calf

The fact that arteria nutricia of the lower epiphysis becomes filled is evidence that anastomoses are present between the various arterial regions. This vessel is a branch of arteria tibialis anterior which is entered retrogradely by opaque substance. In addition, contrast medium leaves the bone via venous channels, both venae tibiales anteriores becoming filled. The corresponding artery is situated between these veins.

4 *Simultaneous filling of the arteries within the tibia after injection into arteria femoralis*

The tibia was examined after removal of joint capsule and muscles (Fig. 27) Arteria nutricia of the diaphysis is seen to be the largest vessel supplying the bone. In the periosteum is a network of arteries, but the cortical channels are so fine that contrast medium does not enter them.

As in the calf the artery entering the upper tibial epiphysis via area inter condylaris anterior is the largest artery of the epiphysis.



Fig 25 Cow Cannula lying in arteria nutricia of the tibial diaphysis. Muscles removed. Urokon A lateral view B, frontal view C, oblique view

1 Arteria nutricia with ascending and descending branches.

2 Contrast medium outside the bone, after passage through cortical paths in the metaphyseal regions.



Fig. 26. Cow. Catheter lying in arteria nutricia of the tibial diaphysis. Urokon.
A, C, and E, frontal views. B, D and F lateral views.
1. Catheter
2. Arteria nutricia and ascending and descending branches.



D E F

3 Main trunk of vena nutricia of the diaphysis filled with contrast medium.
4 Artery to the lower epiphysis.
5 Arteria tibialis anterior
6 Venae tibiales anteriores.

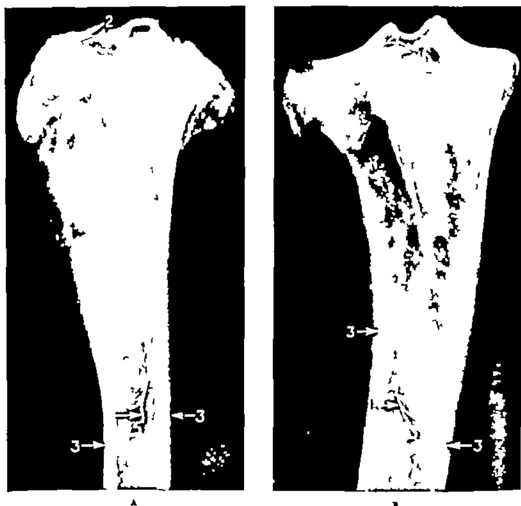


Fig 27 Cow Tibia after injection of Micropaque into arteria femoralis
A and C, lateral views. B and D frontal views. A, a d B, periosteum in situ. C, and D periosteum remo ed.



C



D

1 Arteria nutricia of the diaphysis
2. Arteria nutricia of the epiphysis.
3 Periosteal arteries.

CHAPTER VI

Roentgen Investigations in Human Material

The human material available was limited. My main object was to demonstrate connexions between the various vascular regions of the bones in question Selective angiography is very difficult in human bones the vessels are much smaller than those of the calf

1 *The venous system of the tibial diaphysis of the full term fetus*

In the full term fetus I dissected down to foramen nutricium of the tibial diaphysis, and introduced a blunt cannula into canalis nutricius. The canal is situated posteriorly It opens externally at the junction between the upper and middle thirds of the diaphysis, and passes medially downwards (Fig. 28) On injection through the cannula fairly large ascending and descending veins become filled as far as the metaphyses, where the contrast medium leaves the bone by cortical vessels passing to the veins of the soft parts. In addition a vein is seen perforating the anterior part of the epiphyseal plate, via which venous channels in the anterior part of the epiphysis become filled. These channels drain into a vein leaving the epiphysis in area intercondylaris anterior slightly medial to the mid line A small branch from the epiphyseal veins passing towards the ossification centre is also filled

2. *Intra-osseous and intracartilaginous injections into the upper tibial epiphysis in the child*

Fig 29 illustrates a nearly full term fetus with a small ossification centre at the upper tibial epiphysis The tip of the cannula is lying in the cartilage distal to the centre of ossification. On injection of contrast medium a vein is seen filled passing downwards and laterally to the metaphysis, the antero-lateral part of which becomes filled. The contrast medium leaves the metaphyses chiefly via metaphyseal veins to the veins of the soft parts. Partial filling of vena nutricia of the diaphysis is also obtained.

Fig 30 shows a full term fetus with a cannula lying in the ossification centre of the upper tibial epiphysis. The centre becomes opaque, and from it are filled several venous channels in the epiphyseal cartilage. One of these channels,



Fig 28 Full term fetus. Cannula lying in canalis nutricius of the tibial diaphysis. Urokon.

A, B and C, lateral views. D frontal view

1 Ascending and descending branches of vena nutricia

2 Metaphyseal veins

3 Vein perforating the upper epiphyseal plate

4 Branch of this vein, draining the ossification centre

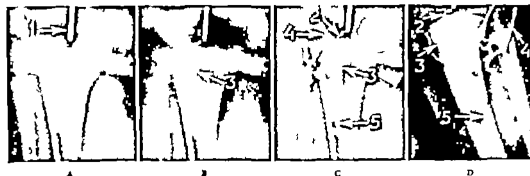


Fig 29 Nearly full term fetus. Cannula introduced into the cartilage of the upper tibial epiphysis. Urokon.

A, B and C, frontal views. D lateral view

1 Cannula.
2 Vein in the anterior part of the epiphysis, passing to the metaphysis.
3 Contrast medium in the metaphysis.
4 Veins of the soft parts.
5 Vena nutricia of the diaphysis, partially filled.



Fig 30 Full term fetus. Cannula introduced into the ossification centre of the upper tibial epiphysis Urokon

A, and B, lateral views. C, frontal view

1 Ossification centre filled.
2 *Vein in the cartilage.*
3 Contrast medium in the anterior part of the metaphysis.

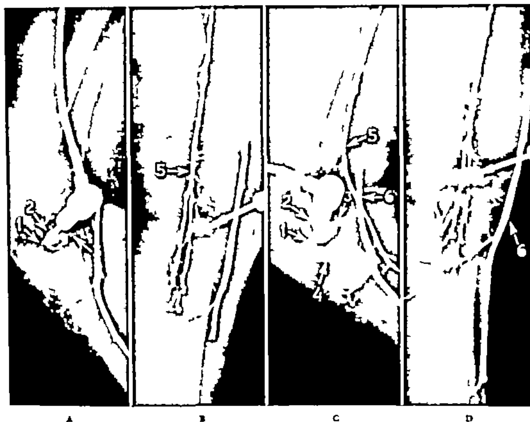


Fig 31 Infa t aged 2 months. Cannula introduced into the ossification centre of the upper tibial epiphysis. Urokon.

A, and C, lateral views. B and D frontal views.

1 Veins in the anterior part of the epiphysis.

2 Veins in the upper part of the epiphysis.

3 Veins in the posterior part of the epiphysis.

4 Filling of veins in the anterior part of the metaphysis.

5 Vena poplitea.

6. Vena saphena.

passing antero-laterally has anastomoses with veins in the metaphysis, which becomes partly filled with contrast medium.

Fig 31 illustrates an intra-osseous injection into the upper tibial epiphysis of a child aged 2 months. The tip of the cannula is lying in the anterior part of the ossification centre. The centre becomes filled with contrast medium, and from it filled veins pass anteriorly superiorly and posteriorly to foramina nutriciae in area intercondylaris anterior eminentia intercondylaris, and area intercondylaris posterior The opaque substance escapes via the capsular veins, and many veins in the soft parts become filled. In this experiment too the anterior part of the metaphysis becomes opaque.

Fig 32 shows the cannula introduced into the upper tibial epiphysis of a 7 year-old child, the tip lying in the middle of the ossification centre. To prevent escape of contrast medium to the capsular veins, the epiphysis and metaphysis are tightly bound with elastic bandages. On injection of contrast medium a longitudinal vein perforating the central part of the epiphyseal plate becomes filled. This vein has anastomotic connexions with metaphyseal veins, which drain via cortical channels to veins of the soft parts on the lateral side of the leg

3 *The arterial system of the lower femoral diaphysis of the fetus*

Fig. 33 shows that the ossification centres of the lower femoral epiphysis have not appeared. The fetus is therefore not full term A blunt cannula is introduced into arteria nutricia of the lower part of the femoral diaphysis. Externally the canal opens posteriorly slightly above the middle of the diaphysis, and passes anteriorly downwards. The main artery is rather tortuous. The fine branches are too narrow to be evident on the radiograms. The contrast medium passes quickly to the metaphysis, which becomes opaque. The contrast leaves by cortical vessels which pass to veins in the soft parts.

4 *The arterial system of the tibial diaphysis of the child*

Fig 34 shows a catheter lying in arteria nutricia of the tibial diaphysis of a 10-month-old child. After leaving the canal the main artery gives off a tortuous ascending branch, and slightly below the centre of the diaphysis another tortuous, descending branch. The contrast medium diffuses rapidly and in subsequent films it is impossible to distinguish small anatomical details. The contrast medium leaves both metaphyses by metaphyseal venous channels.

Fig 35 illustrates a similar investigation on a child aged 6 months. Even opacity of the entire diaphysis up to the epiphyseal plates is obtained, as in the calf Here, too, it is impossible to distinguish the finer branches: the technique is too coarse for this. The contrast medium leaves both ends of the bone by metaphyseal veins.

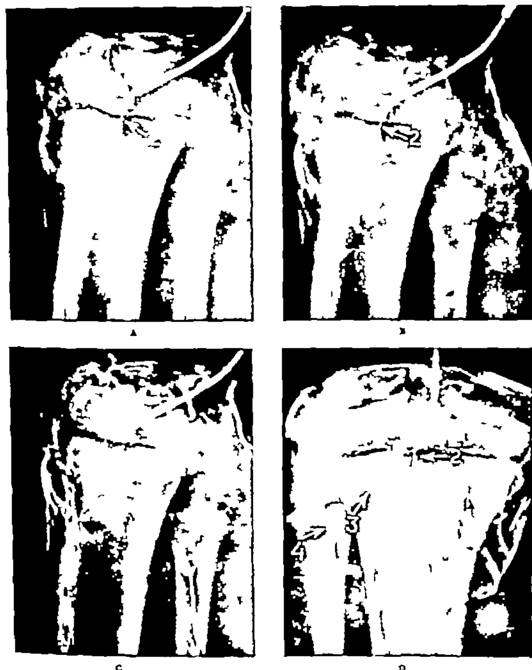


Fig 32 Child, aged 7 years. Cannula introduced into the ossification centre of the upper tibial epiphysis. Urokon

A, B, and C, lateral views. D frontal view

1 Tip of the cannula in the ossification centre

2 Vein perforating the epiphyseal plate at its centre.

3 Metaphyseal veins

4 Veins of soft parts



Fig. 33 Human fetus. Cannula introduced into arteria nutricia of the lower femoral diaphysis. Urokon. A, and E frontal views B, C, D and F lateral views.

1 Tip of the cannula.
2 Main trunk of the artery.
3 Metaphyseal filling.
4 Metaphyseal veins.
5 [Vena] poplitea.



Fig. 34 Infant, aged 10 months. Catheter lying in arteria nutricia of the tibial diaphysis. Urokon. A, B and E, lateral views. C, and D frontal views.

1 Catheter

2 Arteria nutricia

3 Ascending branch.

4 Descending branch.

5 Veins draining the metaphysis.

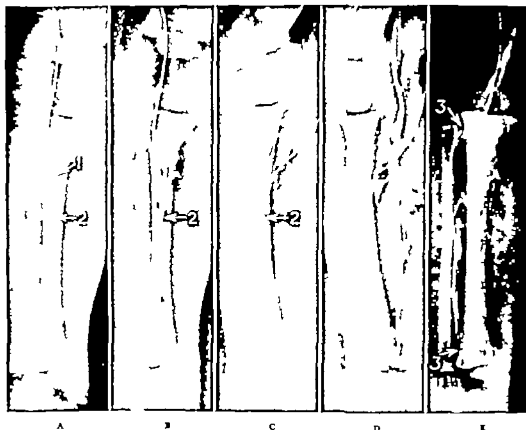


Fig 35 Infant, aged 6 months. Catheter lying in arteria nutricia of the tibial diaphysis. Urokon. A, B and E, frontal views. C, and D lateral views.

1 Tip of the catheter

2. Arteria nutricia.

3 Metaphyseal veins.

In D and E, contrast medium is seen to pass right up to the ep physeal plates.

In fig. 36 the catheter is lying in arteria nutricia of the tibial diaphysis of a child aged 11 years who was tall for his age. The canal is relatively long After leaving the canal the main artery gives off tortuous, ascending branches, and then continues downwards, giving off tortuous, descending branches just below the middle of the diaphysis. Before reaching the epiphyseal plates the contrast medium passes via cortical channels in the metaphyses.

5 *Arteries of the lower femoral metaphysis of the child*

Fig. 37 shows a catheter lying in a branch of arteria poplitea of a 10-month-old child. Large numbers of capsular branches are filled about the upper part of the joint capsule. From these branches arise arteries to the metaphysis at the lower end of the femur and opacity of the metaphysis is thus obtained

6 *Simultaneous filling of arteries in the lower femur and the tibia after injection into arteria femoralis*

Fig 38 illustrates an investigation on a child aged 2 months. All vascular regions are seen to be filled. Dense vascular networks are demonstrated in the periosteum and perichondrium but filling of the cortical vessels of the middle of the diaphysis is not obtained (the contrast medium is unable to penetrate these narrow vessels) The main arteries and major branches in both femur and tibia are well filled but the smaller branches to the metaphyses cannot be distinguished. In the metaphyses, however marked filling is obtained probably both from metaphyseal and diaphyseal arteries. Arteries can be seen running to the centre of the epiphyses, and causing filling of the ossification centres and peripheral arteries arising from penetrating branches of perichondrial vessels can be seen. In the distal tibial epiphysis several vessels in the cartilage are seen filled. No centre of ossification has yet appeared here



Fig. 36. Child, aged 11 years. Catheter lying in arteria nutricia of the tibial diaphysis. Urokon. A and C, lateral views. B and D frontal views.

1 Catheter
2 Main trunk of the artery
3 Tortuous, ascending branch.
4 Tortuous, descending branch
5 Veins leaving the metaphysis

J

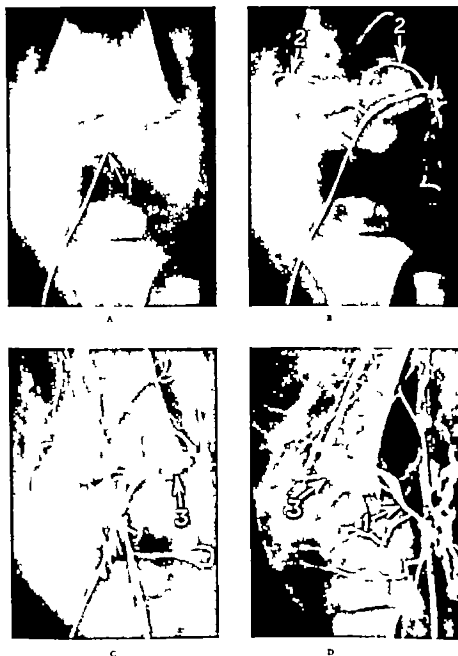
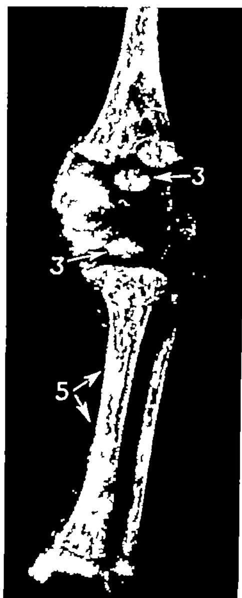


Fig 37 I fant aged 10 months Catheter l} m a branch of arteria popl tea. Urokon A B, and C, frontal \ ew D lateral iew

1 T p of the catheter
2 Capsular arteries
3 F llin of the lower femoral metaphy



A



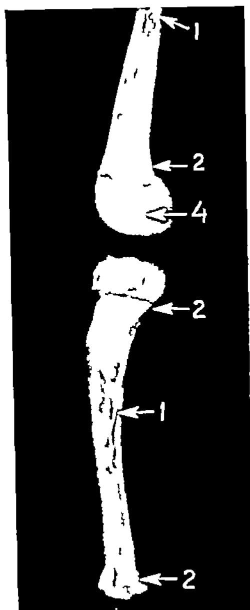
B

Fig. 38 Infant, aged 2 months. The tibia and lower femur after injection of Micropaque into arteria femoralis.

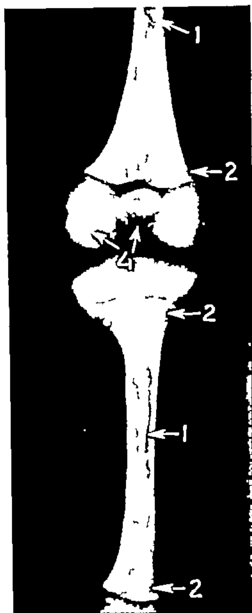
A, and C, lateral views. B and D frontal views.

A, and B, periosteum and perichondrium in situ.

C, and D periosteum and perichondrium removed.



C



D

1 Arteria nutricia of the diaphyses.
2 Metaphyseal filling
3 Filling of epiphyseal ossification centres
4 Arteries in the epiphyseal cartilage
5 Periosteal arteries.

CHAPTER VII

Histological Investigations

Histological investigations were made on preparations from calves, immature human fetuses, and full term fetuses. In the calf I examined canalis nutricius of the tibial diaphysis and the upper tibial epiphysis. In the human material I investigated the upper tibial epiphysis and the lower femoral epiphysis.

The histological investigation is not claimed to be a comprehensive one. The object has been to confirm the roentgen findings, especially with regard to the blood vessels of the cartilage.

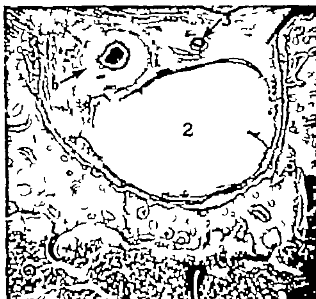
1 *Canalis nutricius of the tibial diaphysis of calf*

In Fig. 39 it is seen that almost the entire lumen of the canal is occupied by a large, thin walled vena nutricia, the thick walled artery lying to one side. If a cannula is introduced into the canal the chances of the tip entering the vein are very great.

A nerve is also seen in the canal accompanying the vessels into the bone. Anyone who has performed intra-osseous injections on living subjects will have found that the procedure is exceedingly painful, even when only physiological saline is injected. Bone is extremely sensitive to changes in pressure within it. In the preparation the cortical canals (both the larger canals of Volkmann and the smaller of Havers) are also clearly visible. Volkmann's penetrate the external and internal bone lamellae, and the Haversian constitute the finer canals of the bone that connect Volkmann's canals with each other

2. *The upper tibial epiphyseal plate in calf*

Fig 40 is a longitudinal section of the tibia through the upper epiphyseal plate. Two longitudinal vascular canals are clearly seen perforating the cartilage. That to the right is divided along almost its entire length whereas only a part of the other is shown in section. Irregularly arranged, hypertrophic cartilage cells are seen in the epiphyseal plate, on the side of the ossification centre On the metaphyseal side the cartilage cells are arranged in columns they increase in size towards the metaphysis.



A



B

Fig 39 Calf one day Transverse sections through canalis nutricius of the tibial diaphysis.
A, upper part of the canal
B middle part of the canal (32, Haematox Eosin).
In A the periosteum forms part of the canal wall.
In B the wall consists entirely of bone.
1 Arteria nutricia 2 Vena nutricia 3 Nerv
4 Volkmann's canals 5 Haversian canals 6. Bone marrow



Fig 40 Calf 2 weeks. Longitudinal section of the upper tibia at the level of the epiphyseal plate (× 30 Haematox Eosin.)

1 Ossification centre of the epiphysis.

2. Metaphysis.

3 Hypertrophic cartilage cells adjacent to the ossification centre.

4 Proliferating cartilage cells with hypertrophic cells adjacent to the metaphysis.

5 Vascular canals perforating the epiphyseal plate.

Fig. 41 is a transverse section through the epiphyseal plate at its junction with the metaphysis the preparation therefore shows partly metaphysis and partly epiphyseal cartilage. The cartilage contains many vascular canals transversely and obliquely cut.

3 *The upper tibial and lower femoral epiphyses in the human fetus*

Fig. 42 shows a longitudinal section through the upper tibial epiphysis of a nearly full term human fetus. There is a small centre of ossification in the epiphysis. Large numbers of vascular canals are seen in the epiphyseal cartilage and these are certainly of great significance in the nutrition of the cartilage and ossification centre.

Fig. 43 illustrates a vascular canal of the cartilage in greater magnification An artery and two large veins are seen No capillaries can be distinguished in the ground substance of the cartilage.

Fig 44 is a longitudinal section through the upper part of the tibia At the level of the epiphyseal plate well developed proliferating and hypertrophic cartilage cells are seen. Immediately above the proliferating cartilage there are large vascular canals, from which arise branches which pass through the epiphyseal plate to the marrow of the diaphysis.

Fig. 45 is a longitudinal section of a similar preparation and shows the entire course of a perforating canal down to the marrow cavity

Fig 46 is a longitudinal section through the knee-joint of a 5 month fetus There are many vascular canals in the cartilage of the femoral and tibial epiphyses, and in the patella. One of the canals of the femoral epiphysis is seen penetrating the hypertrophic cartilage cells to reach the marrow cavity of the diaphysis.



A



B

Fig 41 Calf 2 weeks. Transverse section through the upper tibial epiphyseal plate at its junction with the metaphysis. The section includes both metaphysis and epiphyseal cartilage A, low power view (30). B high-power view (100) (Haemato Eos) There are numerous vascular canals in the cartil ge. These are seen in B between the hypertroph c cartilage cells



Fig 42 Nearly full term human fetus. Longitudinal section through the upper tibial epiphysis (× 3 Haema tox Eosin)

1 Ossification centre of the epiphysis (damaged)

2 Vascular canals in the cartilage



Fig 43 Nearly full term human fetus. Upper tibial epiphysis, showing canal in the cartilage cut across (130, Haematox. Eosin)

1 Artery

2. Veins.

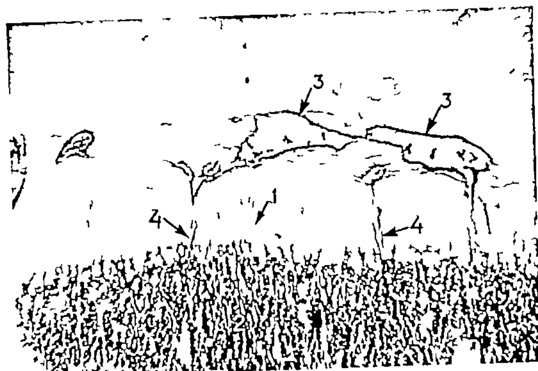


Fig 44 Nearly full-term human fetus Longitudinal section through the upper tibia, at the level of the epiphyseal cartilage (× 40, Haematox Eosin.)

1 Proliferating cartilage cells.

2. Metaphysis

3 Large vascular canals in the epiphyseal cartilage

4 Vascular canals perforating the proliferating cells.



A



B

Fig 45 Nearly full-term human fetus. Longitudinal section through the upper tibia, at the level of the epiphysis. A low power view (20) B high-power view (85). (Haematox. Eosin.)
A vascular canal is clearly seen perforating the proliferating cartilage cells



Fig 46. Human fetus, 5 months. Longitudinal section of the knee joint. A low power view (× 4.5) B, detail of the femur (× 35) (Haematox Eosin).

1 Diaphysis.
2 Femoral epiphysis.
3 Tibial epiphysis.
4 Patella.
5 Vascular canals in the cartilage
6 A vascular canal perforating the epiphyseal plate to reach the marrow cavity of the femur

CHAPTER VIII

Conclusions

1 *Roentgen investigations in calf*

The arteries are accompanied by the veins. The epiphyses and diaphyses are supplied by both central and peripheral vessels.

Vasa nutricia of the diaphysis are the central and also the largest vessels of the tibia. The artery leaves arteria tibialis anterior at an angle of about 90° The main stem follows a straight course in the long canal. In the marrow the large ascending and descending branches are tortuous. The branches of arteria nutricia continue as far as the epiphyseal and apophyseal plates (the latter at tuberositas tibiae) I have never seen any branch of arteria nutricia perforating the epiphyseal or apophyseal plates. The growing regions of the metaphysis adjacent to the apophyseal and epiphyseal plates seem to be highly vascular These regions quickly become opaque on injection of contrast medium into the artery Arteria nutricia gives off many branches throughout the marrow cavity and the capillary system seems to be extensive.

Vena nutricia of the diaphysis is a large vessel that fills out almost the entire lumen of canalis nutricius. Its ascending and descending branches within the middle part of the diaphysis accompany the branches of the artery

The peripheral vessels arise in the periosteum, which is richly vascular The arteries are accompanied by two veins. The vessels running from the periosteal vascular network to the cortex and anastomosing in the cortical vascular canals with branches of vasa nutricia of the diaphysis, are very fine. In the metaphysis these cortical channels, and especially the veins, are larger and can be visualized by injecting contrast medium into vena nutricia of the diaphysis. Injection of Micropaque into arteria femoralis results in some opacity of the metaphyseal regions, the contrast medium entering via the cortex by arteries from the periosteal network.

The central vessels, which are the largest supplying the epiphysis, enter by foramina nutricia, and pass towards the centre branching in all directions. The peripheral vessels are smaller They arise from perichondrial vessels, and anastomose with the central vessels.

The epiphyseal vessels also give off numerous branches to the still unossified cartilage In the calf these can be seen glistening through the joint cartilage.

Vascular canals perforate the epiphyseal plates and run longitudinally to the metaphyses, thus connecting the vascular systems of the epiphysis and metaphysis. These systems therefore anastomose from the growing period

The blood supply of the metaphyses has therefore three sources,

1 vasa nutricia of the diaphysis.

2. the epiphyseal vessels entering through the epiphyseal plates, and

3 the metaphyseal vessels arising in the periosteum and entering through the cortex.

The veins of the bones have no valves, and thus explains the ease with which they can be filled retrogradely As soon as the veins leave the bones, valves are present.

It was interesting to examine the vascular system of tuberositas tibiae, which is an apophysis. The ossification centre has vascular connexions, via the apophyseal plates, with both the epiphysis and the metaphysis. There are arterial connexions with the epiphysis and the metaphysis and the veins anastomose with epiphyseal, *metaphyseal and diaphyseal veins.*

Roentgen examination of tuberculum majus has revealed similar vascular connexions, through the apophyseal plate, with the upper metaphysis of the humerus.

2 *Roentgen investigations in cow*

The various vascular regions have undergone certain changes.

An impression is gained of the considerable reduction in the medullary capillary system that has taken place. In the calf marked opacity of the whole marrow results from intra arterial injection of the contrast medium owing to the rich capillary network but in the cow the picture is quite different the contrast medium entering the veins via a capillary system so greatly reduced that dense filling never takes place.

Vasa nutricia of the diaphysis remain the largest vessels of the long bones, but the arterial branches that in calf supply the growth zones diminish with increasing age and are not found in the adult animal.

In the metaphyses there is anastomosis between vessels from the epiphyses, metaphyses, and diaphysis. The system in the epiphyses remains the same as in the calf with a central vessel and peripheral vessels.

The vessels arising from the periosteum are still most numerous in the metaphyseal regions.

3 *Roentgen investigations in human material*

The human material was, of course very limited but the study has been facilitated by the extensive investigations on calf and cow

It is found that the vascular anatomy of human long bones is closely similar

to that in the calf and cow Thus there are the central vasa nutricia, giving off branches to the epiphyses and diaphysis and the peripheral vessels entering the bone from perichondrium and periosteum. Vascular canals pierce the epiphyseal plates to convey vessels from the epiphyses to the metaphyses. Vessels from all three groups, therefore, anastomose in the metaphysis during the earliest stages of growth.

4 *Histological investigations*

My main object has been to demonstrate the vascular canals of the cartilage, and particularly the canals perforating the epiphyseal plates. I have seen perforating canals in human fetuses, both immature and full term It was striking to see the numerous vascular canals in the cartilage. No capillaries are seen in the ground-substance, the junction between arteries and veins probably taking place in the actual vascular canal Long before the epiphyseal ossification centres appear large numbers of vascular canals are present in the cartilage. The canals therefore arise before the formation of the ossification centre. This disproves the view that the ossification centre develops as a result of inadequate blood supply to the middle of the epiphysis. I have seen numerous vascular canals in the distal femoral epiphysis, patella, and upper tibial epiphysis of a human fetus of only 5 months, and even a vascular canal penetrating to the femoral diaphysis.

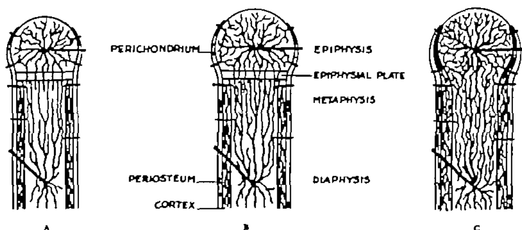


Fig 47 Diagram to illustrate the vessels of a long bone.
A. No ossification centre present in the epiphysis.
B. Ossification centre present.
C. Adult.

Summary

Opinions concerning the vascular anatomy of long bones vary greatly. Earlier researchers, such as LANGER, LEXER, and BIDDER maintained that the vessels of the epiphysis and diaphysis anastomosed from the first.

Most later workers, however, are of the opinion that the epiphyseal plate constitutes a barrier which separates the vascular systems of the epiphysis and diaphysis. This view is shared by NUSSBAUM, RUBASCHEWA, PRIVES, DI MARNEFFE, DALE, HARRIS, and others.

TRUETA too considers the epiphyseal plate to be a barrier, with one exception. He has found that the vessels of the upper femoral metaphysis penetrate the epiphyseal plate in newly born infants. These vessels, he states, disappear early and at 4 years the epiphyseal plate forms an isolating barrier which is not then broken until growth is complete.

The vascular supply of the apophyses has received little attention in the past. BIDDER assumed that vessels pierced the apophyseal plates.

There is a point of great importance concerning the epiphyseal vessels during the cartilaginous stage. Many believe that the vessels on the epiphysis start to develop only when the ossification centres appear. LANGER, BIDDER and others have shown, however, that vascular canals are present in the cartilage long before this.

My investigations were performed on calves, cows and some young human material, the tibia being the main object of study. The following roentgen techniques were employed.

1. Selective angiography via a cannula or catheter introduced into arteria or vena nutricia of the diaphysis or epiphysis. The contrast medium used was 'Urokon (Pharmacia). Serial radiography with rapid film changes enables the passage of the contrast medium through the vessels to be traced.

2. Injection of Micropaque into arteria or vena femoralis followed by examination of the bone before and after removal of the perichondrium or periosteum.

3. Intra-osseous and intracartilaginous injection of Urokon.

The histological investigation was designed to confirm the roentgen findings by demonstrating vascular canals in the epiphyses of calves and human fetuses.

The roentgen investigations in calves showed that arteries accompany veins. In both epiphyses and diaphyses there are central and peripheral vessels. The central vessels pass towards the centre of the bone and branch in all directions

In the diaphysis the main vasa nutricia are the central vessels and in the epiphyses there are large vasa nutricia entering via one or more large foramina nutricia. The peripheral vessels of the diaphyses arise from the periosteal vascular network and those of the epiphyses arise from the perichondrial network. The central and peripheral vessels anastomose.

In the calf arteria nutricia of the diaphysis continues up to the epiphyseal plates, but does not seem to penetrate them. Longitudinal branches of arteria nutricia of the epiphyses on the other hand, perforate both epiphyseal and apophyseal plates. The vessels arising in the periosteum are most abundant in the metaphyseal regions. The growth zones of the metaphyses are richly vascular and their blood supply is secured from diaphyseal metaphyseal and epiphyseal vessels.

The vessels of the epiphyses give off branches not only to the ossification centre but also to the cartilage via vascular canals containing both artery and vein

Branches of the central veins of the epiphyses perforate the epiphyseal plates, and the venous system of a long bone forms a continuous network which has anastomoses with the veins of the soft parts, chiefly via vena nutricia of the diaphysis, the metaphyseal veins, and the epiphyseal veins. The veins are much larger than the arteries. Within the bone they have no valves, these appearing immediately outside the foramina.

Thus it is proved that the epiphyseal plates do not constitute a barrier to the blood vessels during growth. The epiphyseal vessels penetrate them, and vascular connexions between the epiphysis and diaphysis exist from an early stage of growth.

Nor do the apophyseal plates form a barrier Tuberositas tibiae thus has vascular connexions with both epiphysis and metaphysis.

In the cow vasa nutricia of the diaphysis remain the main vessels of the long bones. The arterial branches that in the calf supplied the growth zones diminish with increasing age, and are not found in the adult animal

In the metaphyses of the cow there is considerable anastomosis of epiphyseal, metaphyseal and diaphyseal vessels, as has also been demonstrated by earlier researchers.

In the human material I have demonstrated that the vascular anatomy of the long bones is similar in principle to that of the calf In children there are vascular canals perforating the epiphyseal plates, and vascular connexions between the epiphyses and diaphyses are present from an early stage.

By means of histological studies I have confirmed the presence in calves and human fetuses of vascular canals perforating the epiphyseal plates. During growth the epiphyseal cartilage contains abundant vascular canals, and these develop at an early stage, long before the appearance of the ossification centres.

Zusammenfassung

Es bestehen divergierende Auffassungen über die Blutgefässverhältnisse in langen Röhrenknochen während des Wachstums.

Ältere Forscher wie LANGER, LEXER und BIDDER sind der Ansicht, dass die Gefässe in den Epiphysen und der Diaphyse bereits während des Wachstums miteinander anastomosieren

Die meisten späteren Forscher sind doch der Ansicht, dass die Epiphysenfugen eine Barriere für die Blutgefässe bilden so dass die Gefässysteme der Epiphysen vom Gefässystem der Diaphyse getrennt wären Dieser Auffassung sind NUSSBAUM, RUBASCHEWA, PRIVES DE MARNEFFE, DALE, HARRIS u. a.

Auch TRUETA erachtet die Epiphysenfuge als Barriere, doch mit einer Ausnahme: er fand dass bei Neugeborenen die Epiphysenfuge im proximalen Femur von Metaphysengefässen durchbohrt wird. Diese Gefässe verschwinden relativ rasch so dass bereits im Alter von 4 Jahren die Epiphysenfuge eine isolierende Barriere bildet, die nicht vor dem Abschluss des Wachstums durchbrochen wird

Bisher wurde das Gefässystem der Apophysen nur wenig beachtet. Bidder vermutet doch, dass Gefässe existieren die die Apophysenfugen perforieren

Das Problem der Epiphysengefässe während des Knorpelstadiums ist eine wichtige Frage. Viele sind der Meinung, dass die Epiphysengefässe erst entstehen, wenn die Knochenkerne angelegt werden LANGER, BIDDER u. a. haben doch gezeigt, dass im Knorpel Gefässkanale lange Zeit vor der Entwicklung des Knochenkernes bestehen.

Meine Untersuchungen wurden ausgeführt an separierten Gliedmassen von Kälbern, Kühen und an einer kleinen Serie menschlichen Materials während der Wachstumsperiode Das hauptsächlich verwendete Objekt war die Tibia. Für die Röntgenuntersuchung verwendete ich folgende Methoden

1 Die selektive Angiographie mit der Kanüle oder Katheter in der Arteria oder Vena nutricia sowohl der Diaphyse wie auch der Epiphyse. Als Kontrastmittel wurde Urokon (Pharmacia) verwendet. Es passiert ohne Schwierigkeit durch das Kapillarsystem so dass bei arterieller Injektion auch die drainierenden Venen kontrastgefüllt werden Mittels raschen Filmwechsels konnte die Kontrastpassage durch die Blutgefässe verfolgt werden

2. Injektion von Micropaque in die Arteria resp Vena femoralis, danach Untersuchung des Röhrenknochens sowohl mit wie ohne Periost und Perichondrium.

3 Intraossöse und intracartilaginäre Injektionen mit Urokon als Kontrastmittel.

Die histologischen Untersuchungen dienten dem Nachweis von Gefässkanälen in den Epiphysen beim Kalb und bei reifen und unreifen menschlichen Fetus.

Die Röntgenuntersuchungen am Kalb zeigten, dass Arterien und Venen einander begleiten Sowohl in den Epiphysen wie auch in den Diaphysen bestehen teils zentrale, teils periphere Gefässe Die zentralen Gefässe kommen von den grossen Foramina nutricia und verzweigen sich strahlenförmig in alle Richtungen. In den Diaphysen darstellen die eigentlichen grossen Vasa nutricia die zentralen Gefässe, während in den Epiphysen ebenfalls grosse Vasa nutricia vorkommen, die durch ein oder mehrere grosse Foramina nutricia in das Epiphysenzentrum gelangen Die peripheren Diaphysengefässe entspringen aus dem periostalen Gefässnetz, die peripheren Epiphysengefässe aus dem perichondralen Gefässnetz. Die zentralen und peripheren Gefässe anastomosieren miteinander

Die Arteria nutricia in der Diaphyse des Kalbes erreicht mit seinen Verzweigungen die Apo- und Epiphysenfugen, ohne diese sichtbar zu perforieren. Die Arteria nutricia in den Epiphysen perforiert hingegen mit longitudinal verlaufenden Verzweigungen sowohl die Epiphysenfugen, wie auch bei der proximalen Tibia, die Apophysenfuge. Die vom Periost ausgehenden Gefässe sind am reichlichsten in den Metaphysenzonen vorhanden. Die Wachstumszonen der Metaphysen sind reich vascularisiert, ihre Blutgefässversorgung ist gesichert durch diaphysäre, metaphysäre und epiphysäre Gefässe.

In den Epiphysen verzweigen sich die Gefasse nicht nur im Knochenkern sondern auch in Gefässkanälen des Knorpels, in welchen sowohl Arterien wie auch Venen verlaufen

Verzweigungen der zentralen Venen der Epiphysen perforieren die Epiphysenfugen so dass die Venensysteme eines langen Röhrenknochens ein zusammenhängendes Netz bilden Dieses Venennetz steht mit den Weichteilvenen in Verbindung hauptsächlich via die Vena nutricia der Diaphyse, die Metaphysenvenen und die Epiphysenvenen die durch die grossen Foramina nutricia der Epiphysen gehen. Die Venen haben ein weites Kaliber im Verhältnis zu den Arterien. Die Venen innerhalb des Knochens haben keine Klappen, doch sobald sie die Foramina nutricia verlassen, sind sie mit Klappen versehen.

Die Epiphysenfugen bilden infolgedessen keine Barriere für Blutgefässe während der Wachstumsperiode. Die Epiphysengefässe perforieren die Fugen und bilden eine Gefässverbindung zwischen Epiphysen und der Diaphyse, die bereits wahrend der Wachstumsperiode existiert.

Auch nicht die Apophysenfugen bilden eine solche Barriere. Die Tuberositas tibiae hat infolgedessen Gefässverbindungen sowohl zur Epiphyse wie auch zur Metaphyse

Beim erwachsenen Rind bewahren die Vasa nutricia der Diaphyse die Rolle

des grössten Gefässes des Röhrenknochens. Mit zunehmendem Alter des Kalbes werden die Arterienverzweigungen, die zu den Wachstumszonen verlaufen, zunehmend rückgebildet und fehlen beim erwachsenen Rind. Beim erwachsenen Rind anastomosieren die Epiphysen-, Metaphysen- und Diaphysengefässe reichlich. Dies wurde auch durch frühere Untersuchungen gezeigt.

Am menschlichen Material konnte ich zeigen, dass die Gefässverhältnisse prinzipiell mit denen beim Kalbe übereinstimmen. Bei Kindern bestehen durch die Epiphysenfugen perforierende Gefässkanäle, also bereits während der Wachstumsperiode vorhandene Verbindungen zwischen den Gefässystemen der Epiphysen und der Diaphyse.

Durch histologische Untersuchungen konnte ich die perforierenden Gefasskanale durch die Epiphysenfugen verifizieren, und zwar sowohl beim Kalb wie auch bei reifen und unreifen Menschenfetus. Der Epiphysenknorpel enthält während der Wachstumsperiode reichlich Gefässkanäle. Diese werden während eines frühen Stadiums angelegt, lange Zeit vor der Entwicklung der Epiphysenknochenkerne.

Résumé

Les opinions sur la vascularisation des os longs pendant la croissance sont divergentes.

Des auteurs anciens comme LANGER, LEXER et BIDDER pensent que les vaisseaux *des épiphyses et de la diaphyse sont déjà anastomosés entre eux pendant* la croissance.

La plupart des chercheurs plus récents sont cependant d'avis que les cartilages de conjugaison épiphysaires opposent une barrière aux vaisseaux, de sorte que le système vasculaire des épiphyses est séparé du système vasculaire de la diaphyse. C'est l'opinion de NUSSBAUM, RUBASCHEWA, PRIWES, DE MARNEFFE, DALE, HARRIS et plusieurs autres.

TRUETA aussi pense que le cartilage de conjugaison épiphysaire est une barrière, avec une exception chez le nouveau né et pendant les quatre premières années de la vie, des vaisseaux métaphysaires perforent le cartilage de conjugaison épiphysaire de l'extrémité supérieure du fémur

Le système vasculaire des apophyses ne semble pas avoir été étudié en détail jusqu'à présent. BIDDER suppose cependant qu'il existe des vaisseaux perforant le cartilage de conjugaison des apophyses

Une question importante est celle des vaisseaux des épiphyses pendant le stade de formation du cartilage. Plusieurs auteurs pensent que les vaisseaux des épiphyses n'apparaissent qu'en même temps que se forment les centres d'ossification. *LANGER, BIDDER et plusieurs autres ont cependant montré qu'il existe des* canaux vasculaires bien avant le développement du centre d'ossification

Mon matériel d'étude se compose de veaux de vaches et d'une petite série de sujets humains en période de croissance. Les recherches ont porté principalement *sur* le tibia. Pour l'examen radiologique j'ai eu recours aux méthodes suivantes

1 Angiographie sélective par une canule ou un cathéter dans l'artère ou la veine nourricière de la diaphyse ou de l'épiphyse. Comme moyen de contraste, je me suis servi d'Urokon (Pharmacia) Par changement rapide des films, il est possible de suivre le passage du contraste dans les vaisseaux.

2. Injection de Micropaque dans l'artère ou la veine fémorale suivie d'examen des os longs avec et sans périoste et périchondre.

3 Injections intra-osseuses et intracartilagineuses d'Urokon

Les études histologiques ont eu pour but de montrer les canaux vasculaires des épiphyses chez le veau et chez des foetus humains à terme et avant terme.

L'examen radiographique du veau a prouvé que les artères et les veines

s'accompagnent. Dans les épiphyses ainsi que dans les diaphyses il y a des vaisseaux centraux et des vaisseaux périphériques. Les vaisseaux centraux se dirigent vers le centre et se ramifient dans toutes les directions. Dans les diaphyses, les gros vaisseaux nourriciers constituent les vaisseaux centraux et dans les épiphyses il y a de gros vaisseaux nourriciers qui par un ou plusieurs trous vasculaires du canal nourricier se dirigent vers les parties centrales de l'épiphyse. Les vaisseaux périphériques des diaphyses viennent du réseau vasculaire périostal et ceux des épiphyses du réseau vasculaire périchondral. Les vaisseaux centraux et les vaisseaux périphériques s'anastomosent entre eux.

Chez le veau, l'artère nourricière de la diaphyse se ramifie jusqu'aux cartilages de conjugaison épiphysaire et apophysaire, mais ne semble pas les perforer. L'artère nourricière des épiphyses par contre, perfore aussi bien les cartilages de conjugaison épiphysaires que les cartilages des conjugaison apophysaires par de petits rameaux longitudinaux. C'est dans les zones métaphysaires que les vaisseaux venant du périoste sont le plus nombreux. Les zones de croissance des métaphyses ont une riche vascularisation assurée par des vaisseaux diaphysaires, métaphysaires et épiphysaires.

Dans les épiphyses, les vaisseaux se ramifient non seulement dans le centre d'ossification mais aussi dans le cartilage, à l'intérieur de canaux vasculaires où passent des artères et des veines.

Des petits rameaux des veines centrales des épiphyses perforent les cartilages de conjugaison et le système veineux d'un os long forme un réseau ininterrompu de veines. Celui-ci communique avec les veines des parties molles par la veine nourricière de la diaphyse, les veines métaphysaires et les veines épiphysaires par les grands orifices vasculaires du canal nourricier des épiphyses. Le calibre des veines est grand en comparaison de celui des artères. Dans l'os, les veines n'ont pas de valvules, mais il y en a juste à la sortie de l'orifice vasculaire du canal nourricier.

Les cartilages de conjugaison épiphysaires ne constituent donc pas une barrière pour les vaisseaux pendant la croissance. Les vaisseaux épiphysaires les perforent, de sorte qu'il y a déjà pendant la croissance communication entre la diaphyse et les épiphyses.

Les cartilages de conjugaison apophysaires ne constituent pas non plus une barrière. La tubérosité tibiale antérieure a des communications vasculaires avec l'épiphyse ainsi qu'avec la métaphyse.

Chez la vache, les vaisseaux nourriciers de la diaphyse continuent à jouer le rôle de vaisseau principal de l'os long. Les ramifications artérielles qui chez le veau se dirigent vers les zones de croissance se sont considérablement réduites avec l'âge et font défaut chez la vache. Dans les métaphyses il y a chez la vache une riche formation anastomotique de vaisseaux épiphysaires, métaphysaires et diaphysaires, fait déjà constaté par d'autres auteurs.

Sur le matériel humain j'ai pu mettre en évidence que la disposition des rapports vasculaires est en principe analogue à celle du veau. Chez l'enfant, il existe des canaux vasculaires perforant les cartilages de conjugaison épiphysaires, de sorte qu'il y a déjà pendant la croissance communication entre le système vasculaire de l'épiphyse et celui de la diaphyse.

Par des examens histologiques j'ai pu vérifier l'existence de canaux vasculaires perforant les cartilages de conjugaison épiphysaires aussi bien chez le veau que chez des foetus humains à terme et avant terme. Le cartilage des épiphyses est pendant la croissance abondamment pourvu de canaux vasculaires et ceux-ci existent à un stade précoce, bient avant le développement des centres d'ossification des épiphyses.

References

BARGMANN, W.: Histologie und Mikroskopische Anatomie des Menschen. Georg Thieme Stuttgart 1956.

BIDDER, A.: Osteobiologie. Arch. Anat. 68 (1906) 137

BUCHER, O.: Histologie und Mikroskopische Anatomie des Menschen. H Huber Bern/Stuttgart 1956.

DALE, G G HARRIS, W R.: Prognosis of epiphyseal separation An experimental study J Bone and Joint Surg. 40–B (1958) 116

DOAN, C.: The capillaries of the bone marrow of the adult pigeon Bull. John Hopkins Hosp 33 (1922) 222.

ECOIFFIER, J PROY D GRIFFIE, R. et CATACH, D Étude du réseau veineux dans les os longs du lapin Archives d Anatomie 1 (1957) 101

GIDLUND, A: Development of apparatus and methods for roentgen studies in haemodynamics. Acta radiol. Suppl. 130 (1956)

GRÉGOIRE, R., CARRIÈRE, C. Circulation artérielle intra-osseuse de femur et du tibia. L Ass. des Anatom. 16 (1921), 179

HASHIMOTO M. Über das gröbere Blutgefässystem des Kaninchenknochenmarks. Fukuoka Acta Medica 28 (1935), 371

—: Über das kapilläre Blutgefässystem des Kaninchenknochenmarks. Transactiones Societatis Pathologicae Japonicae 26 (1936) 300

HARRIS, H A.: The vascular supply of bone with special reference to the epiphysial cartilage. Journal of Anatomy 64 (1930), 3

HULTH, A: Intra-osseous venographies of medial fractures of the femoral neck. Acta Chir Scandinavia Suppl. 214 (1956)

LANGER, K.: Über das Gefässystem der Röhrenknochen. Denkschriften der kaiserlichen Akademie der Wissenschaften, 36 (1876) 1

LEWIS, O J: The blood supply of developing long bones with special reference to the metaphyses. J Bone and Joint Surg 38–B (1956), 928

LEXER E.: Untersuchungen über Knochenarterien mittelst Röntgenaufnahmen injizierten Knochen. A Hirschwald, Berlin 1904

DE MARNEFFE R.: Recherches morphologiques et expérimentales sur la vascularisation osseuse Acta chir Belg. 50 (1951) 469 568 681

MAXIMOW and BLOOM: A Textbook of Histology W B Saunders Company Philadelphia 1937

NUSSBAUM, A. Anatomie der Knochenarterien Archiv für klin. Chir 126 (1923) 40.

RATTI, A., AGUZZI, A., MARLEY A. Osteomedullografia. Atti del XIX Congresso nazionale Vol II Società Italiana di Radiologia Medica. Baster Editori, Roma 1956

ROGERS, W GLADSTONE, H.: Vascular foramina and arterial supply of the distal end of the femur J Bone and Joint Surg 32–A (1950) 867

RUBASCHEWA, A., PRIWES, M. G Blutversorgung der langen Röhrenknochen des Hundes. Z. Anat. 98, 3 (1932) 361

SPIESS, H: Die Knochenmarkinfusion mit Kontrastflüssigkeit im Röntgenbilde Monatschr f Kinderheilkunde 98 (1950), 217

TRUETA, J HARRISON M. H M. The normal vascular anatomy of the femoral head in adult man. J Bone and Joint Surg 35–B (1953) 442.

TRUETA, J The normal vascular anatomy of the human femoral head during growth. J Bone and Joint Surg 39–B (1957) 358